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19 July 62

APOLLO RENDEZVOUS SIMULATOR STUDY [U]

CONTRACT NAS w —413(HS-625)

TECHNICAL DATA REPORT

VOLUME VII

VEHICLE ANALYSIS — WEIGHT ANALYSIS [U]

12 JULY 1962

REPORT NO. 324.4

ASTRONAUTICS DIVISION

CHANCE VOUGHT CORP

BOX 6267   DALLAS 22, TEXAS

GROUP 4
Downgraded at 3 year
intervals; declassified
after 12 years

C 66-3137

Report No. 324.4
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VEHICLE ANALYSIS - WEIGHT ANALYSIS [U]

Apollo Rendezvous Simulator Study [U]

Contract NASw - 413(HS-625)

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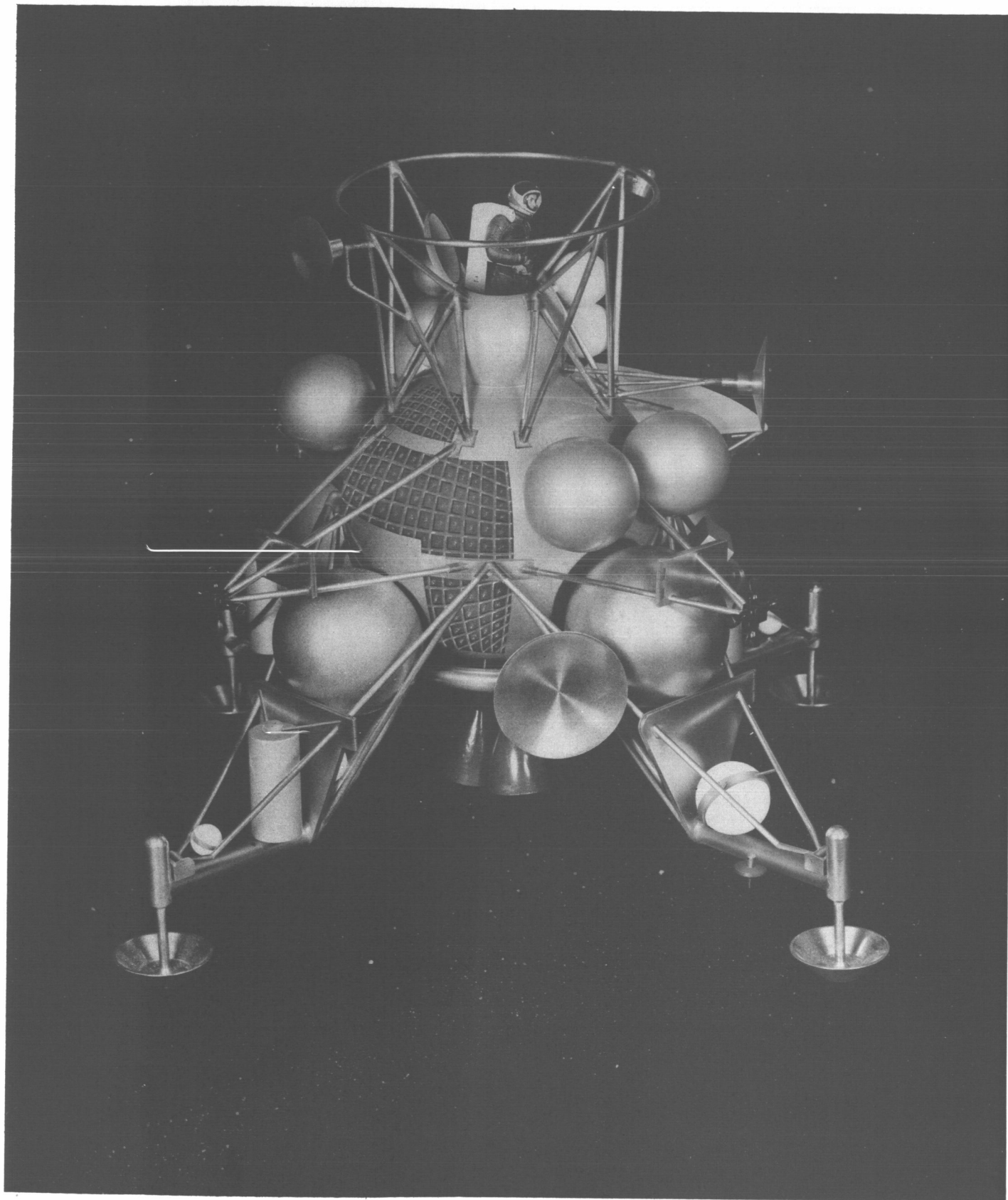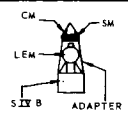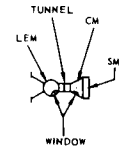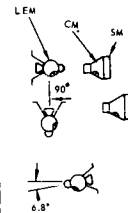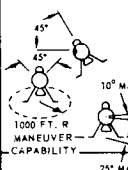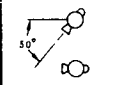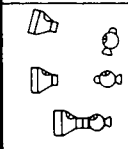
LUNAR EXCURSION MODULE

MISSION PHASE	PHASE IS TERMINATED BY	EVENT SEQUENCE	LEM ORIENTATION	TIME EVENT	TIME CUM (hrs)	ALTITUDE	DELTA V (Ideal) fps	LEM WEIGHT (Earth lbs)
EARTH LAUNCH & PARKING ORBIT	BURNOUT AT TRANSLUNAR INJECTION	● BOOST INTO EARTH PARKING ORBIT ● COAST IN PARKING ORBIT ● TRANSLUNAR INJECTION FROM EARTH PARKING ORBIT		300 sec. 1.5 hrs. 135 sec.	.1 1.6 1.7	0 150 NM (earth)	29,760 10,700	29,290
TRANSLUNAR	START OF RETRO INTO LUNAR ORBIT	● COAST ● SEPARATE & JETTISON ·ADAPTOR ● DOCK COMMAND MODULE – SERVICE MODULE INTO LEM ● SEPARATE SIV B FROM LEM ● PERFORM MIDCOURSE CORRECTION (S) ● COAST TO START OF LUNAR ORBIT INJECTION		72 hrs.	73.7		400	29,290
LUNAR ORBIT & ORBIT TRANSFER	START OF GROSS DECELERATION	● RETRO INTO LUNAR ORBIT ● ESTABLISH ORBIT EPHEMERIS ● TRANSFER ONE CREW MEMBER FROM COMMAND MODULE & INITIATE CHECKOUT OF LEM ● TRANSFER OTHER CREW MEMBER & COMPLETE CHECKOUT ● COAST TO RETRO POINT, OVERPASS LANDING SITE ONCE ● SEPARATE LEM FROM CM ● RETRO TO INITIATE TRANSFER ORBIT ● COAST IN TRANSFER ORBIT ● OBTAIN NAVIGATION DATA		200 sec. 150 min. 26 sec. 29 min.	73.8 76.3 76.3 76.8	59 NM (Lunar) 59 NM	3,000 255	29,894
LUNAR DESCENT	LUNAR TOUCHDOWN	● INITIATE GROSS DECELERATION ● HOVER & LATERAL MOVEMENT. OBSERVE LANDING SITE ● DESCENT TO SURFACE		333 sec. 105 sec.	76.9 77.0	62,000 FT 100 FT 10 FT	5,912 590	15,157
LUNAR SURFACE STAY	START OF LUNAR LAUNCH	● STAGE LANDING GEAR ASSEMBLY ● INSPECTION OF LEM STRUCTURES & SYSTEMS ● EXPLORATION & EXPERIMENTATION ● MAINTENANCE AS REQUIRED ● CHECKOUT & COUNTDOWN		24 hrs.	101.0			11,042
LUNAR ASCENT & ORBIT TRANSFER	COMPLETION OF PLANE CHANGE WITH MAIN ENGINE	● GROSS LAUNCH AND INJECTION HOHMANN TRANSFER ORBIT ● COAST TOWARD ORBIT CONTAINING CM–SM & EXECUTE PLANE CHANGE WITH MAIN ENGINE		228 sec. 43.7 min.	101.1 101.8	50,000 FT.	5,780 25	
LUNAR ORBIT RENDEZVOUS	START OF TRANSEARTH INJECTION	● COAST TO ORBIT CONTAINING CM–SM ● TERMINAL RENDEZVOUS MANEUVERS ● DOCKING ● CREW TRANSFER FROM LEM TO CM ● SEPARATE & ABANDON LEM – COAST TO TRANSEARTH INJECTION POINT		13.3 min. 2.7 min. 14.5 min. 42.8min.	102.0 102.1 102.3 103.0	70,000 FT 59 NM	193 10	5,972 5,248
TRANSEARTH	RE-ENTRY INTO EARTH'S ATMOSPHERE	● TRANSEARTH INJECTION OF COMMAND & SERVICE MODULES ● COAST ● EFFECT MIDCOURSE CORRECTION(S) ● SEPARATE & JETTISON SERVICE MODULE ● COAST PRIOR TO RE-ENTRY	NOT APPLICABLE	200 sec. 72 hrs.	103.1 175.1		3,000 400	N.A.
EARTH RE-ENTRY & LANDING	EARTH LANDING RECOVERY	● RE-ENTRY OF COMMAND MODULE ● EARTH LANDING ● RECOVERY OF COMMAND MODULE & CREW		0.5 hrs.	175.6			

LUNAR ORBIT RENDEZVOUS MISSION OPERATION PLAN – MISSION CHARACTERISTICS

PREFACE

The Lunar Orbit Rendezvous mode for accomplishing the Apollo manned lunar landing has been studied by the Chance Vought Astronautics Division under contract to Office of Systems, Manned Flight, NASA Headquarters. The objective of this study was to make a systematic and thorough analysis of the Lunar Orbit Rendezvous Mission (LOR) with the end products to be (1) A recommended LOR mission, (2) A recommended vehicle design, and (3) A development plan for accomplishing the over-all mission. The study was performed under the title, 'Apollo Rendezvous Simulator Study, Contract NASw-413', and is classified Confidential.

The study results are presented in two parts:

Part 1 - SUMMARY REPORT - An over-all summary of the significant results of the study.

Part 2 - A complete TECHNICAL DATA REPORT in 8 volumes.

Volume I   MISSION SUMMARY AND TRAJECTORY ANALYSIS

Volume II   VEHICLE ANALYSIS - DESIGN

Volume III VEHICLE ANALYSIS - PROPULSION

Volume IV   VEHICLE ANALYSIS - CONTROLS AND ELECTRONICS

Volume V   VEHICLE ANALYSIS - CREW INTEGRATION AND SAFETY

Volume VI   VEHICLE ANALYSIS - ENVIRONMENTAL CONTROL SYSTEM

Volume VII VEHICLE ANALYSIS - WEIGHT ANALYSIS

Volume VIII DEVELOPMENT PROGRAM

The study was conducted within the over-all program philosophy and constraints included in the NASA contract statement of work for this study. The principal constraints established in this statement of work are as follows:

- No changes in the Apollo spacecraft design are expected from the result of this study.

- No changes in the Saturn C-5 launch vehicle configuration are expected from the result of this study.

In addition to the contract statement of work, NASA Headquarters defined a series of guidelines for the conduct of the study which were summarized in 'Minutes of Lunar Orbit Rendezvous Meeting, April 2 - 3, 1962'. The principal guidelines established by this document are as follows:

- The Lunar Excursion Module (LEM) will have a point landing (±1/2 mile) capability.

- The LEM will have redundant guidance and control for each phase of the lunar maneuvers.

- Both automatic and manual guidance and control systems are to be considered in this redundant capability.

- Radio aids, including use of a beacon and/or transmitter on the lunar surface to provide a completely automatic landing are to be studied.

- The suggested hover capability for the LEM is one minute at 100 ft. altitude plus 45 seconds of translation time cver the lunar surface. This requirement will be studied further.

- The LEM should include two crew members.

- The LEM should have a pressurized cabin which has a capability for a one week operation.

- Access to the LEM from Apollo during the earth-moon phase should be possible.

- The possibility of keeping the LEM attached to the space-craft on the return moon-earth phase shall be considered.

In general, the philosophy and guidelines established for the study required an examination of all of the important possibilities and techniques for accomplishing the mission. The resulting recommended mission and vehicle design are therefore more comprehensive than a minimum mission and vehicle. In addition to this recommended vehicle, data are presented showing the effect on vehicle weight of mission and design parameters such as lunar stay time, number of crew members, etc.

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17.0 WEIGHT ANALYSIS

INTRODUCTION

In light of the overall cost of carrying a pound of payload, the importance of weight in this program cannot be overemphasized. On this basis, it is the intent and purpose of the weight section not only to provide superior weight estimates for the HS-625 vehicle, but also to provide analysis and justification of the weights presented.

A conservative approach, restrained by the launch vehicle capability, is reflected in the weight data presented. In addition to this, a specific weight allowance was made for mission flexibility and growth which is likely to occur during the design of a vehicle as advanced as the LEM.

The method used in establishing weight estimates and weight control is based on a philosophy of team effort. Structural weights are calculated from layouts and engineering sketches resulting from stress analyses of the configuration. Weight allowances for cutout penalties, attachment hardware, etc. are added based on this contractor's experience with actual hardware. System weight estimates are made initially by specialists in the particular field (guidance, communications, etc.). The weight engineer adds weight for installation, circuitry, plumbing, and penalties. In this way a complete, installed weight is derived. This basic data is then checked analytically and compared statistically and then refined estimates are made. Inputs from various vendors are synthesized and used in conjunction with applicable data from current programs, in this case, Mercury, Apollo, and Scout. This method has been used with excellent results on past aircraft and missile programs. For this reason there is a high degree of confidence that the LEM weights are realistic.

Figure 17-1 GENERAL ARRANGEMENT

17.1 WEIGHT, BALANCE, AND INERTIAL DATA SUMMARY

The data presented in this section is based on the selected configuration shown in Figure 17-1 .

17.1.1 Spacecraft Weight Summary

A summary of the spacecraft weight configured with the HS-625 vehicle is presented in Table 17-I. The Lunar Excursion Module is divided into three sections including the Crew Station, Propulsion Stage, and Landing System. Weights for the Service and Command Modules are based on inputs from NASA with adjustments as shown in the spacecraft weight buildup, Table 17-II. The Launch Vehicle-to-Apollo Adapter weight was calculated from an engineering sketch.

17.1.2 Spacecraft Weight Buildup and Mission Weight History

Certain adjustments had to be made to the Command and Service Modules as a result of the LOR concept. These additions are shown in the first part of Table 17-II.

The weight of the spacecraft is given at discrete points throughout the mission. Items which are consumed, expended, or staged are listed separately, to simulate the actual mission.

17.1.3 Weight, Balance, and Moment of Inertia Summary

The axis system shown in Figure 17-3 should be referred to in connection with the data presented in Table 17-III. Approximately 120 item weights and centers of gravity were used in calculating the balance and inertia data, rather than estimating only a few large sections. This was done in order to provide more accurate data for design of the Automatic Control and Stabilization System, etc. Local moments of inertia were calculated for each large item and propellant tank. There was no additional effort made to re-position items to take out the slight unbalance in Y and Z. Achieving this situation is not considered a major problem.

The existing IBM 7090 routine will be used for future detailed analyses of the HS-625 vehicle. This routine produces weight, balance, and inertial data of very high quality on standard, IBM printout sheets.

LAUNCH
ESCAPE TOWER

APOLLO
COMMAND MODULE

APOLLO SERVICE
MODULE

CREW
STATION

LUNAR
EXCURSION
MODULE

PROPULSION

LANDING
SYSTEM
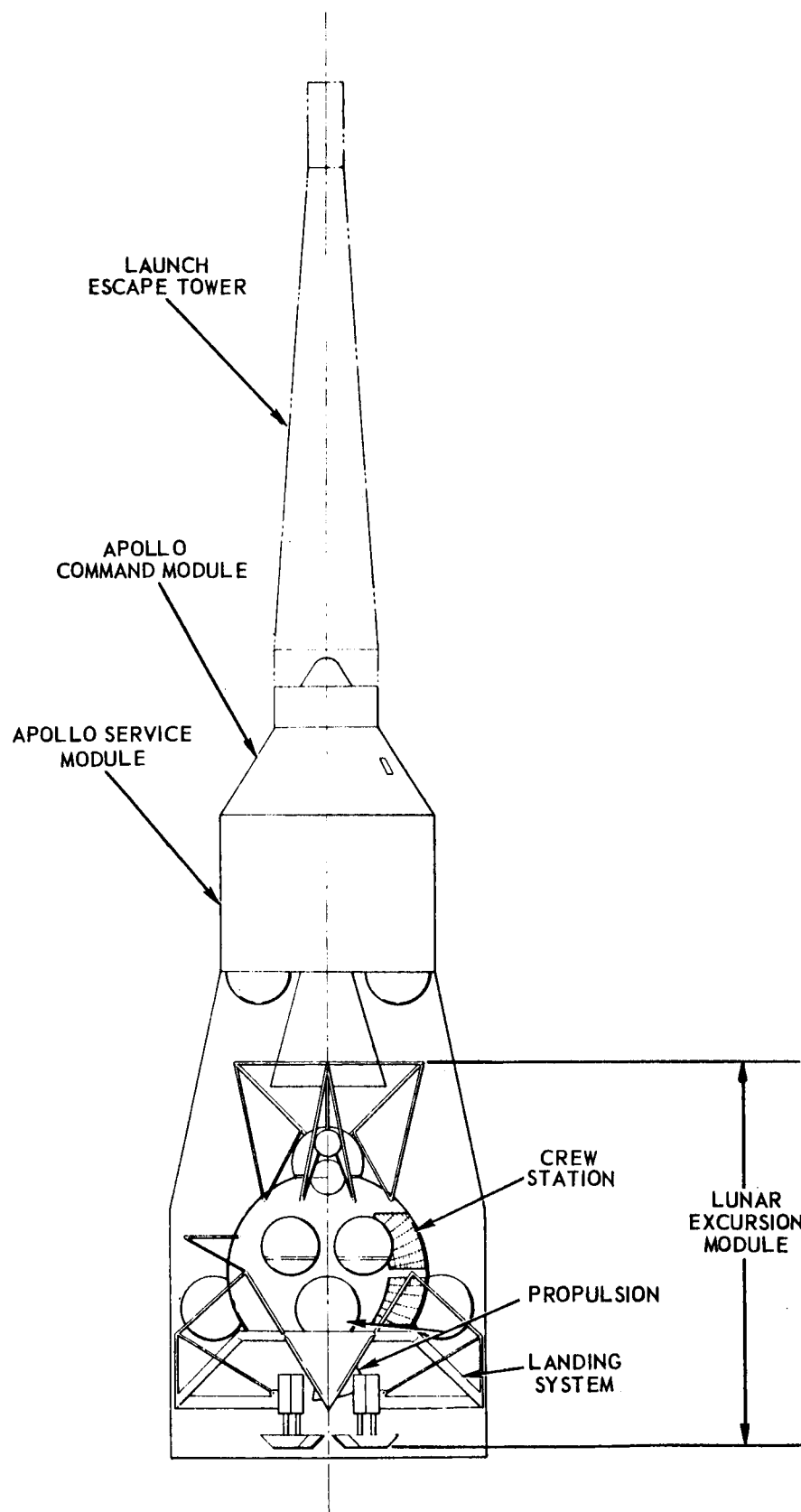
Figure 17-2 SPACECRAFT AT LAUNCH SITE

TABLE 17-I

SPACECRAFT WEIGHT SUMMARY

(At Earth Launch Site)

	Weight — Earth		Pounds
Lunar Excursion Module			29,290
Crew Station		5,027	
Structure	(987)		
Body	883		
Engine Support	52		
Airlock	52		
Systems	(2914)		
Navigation & Guidance	262		
Stabilization & Control	33		
Reaction Control System	492		
Environmental Control System	504		
Electrical Power	888		
Communications	128		
Instrumentation	78		
Scientific Payload	215		
Displays	141		
Crew, Pressure Suit	*		
Self Maneuv. Unit, Environ. Backpk.	*		
Seat	40		
Food	4		
Water	**		
Furnishings	3		
Electronic Support System	26		
Docking	100		
Growth Allowance ***	(1126)		
Propulsion Stage		23,288	
Inert	2122		
Propellant	21166		
Landing System		975	
Adapter (Launch Vehicle-to-Apollo)			3,230
Service Module			40,085
Command Module			10,660
SPACECRAFT (without Launch Escape Propulsion System and LEM-To-Launch Vehicle Support)			83,265

* These items, totalling 615 pounds, are transferred from the Command Module during the translunar phase.

** Included in the Environmental Control System. - water to replace the initial 53 pounds (for cooling, drinking, etc.) is produced by fuel cells.

*** This is 25% of the weight of Crew Station structure and systems at the the time of separation of the LEM from the Spacecraft. The Landing System and Propulsion have been sized for this condition.

TABLE 17-II

SPACECRAFT WEIGHT BUILDUP & MISSION WEIGHT HISTORY

		Weight - Pounds	
Lunar Excursion Module		29,290	
Adapter/Fairing		3,230	
Service Module	(40,085)	40,085	
Basic NAA SM*	38,325		
Additional Propellant Required	1,674		
Tankage for additional propellant	71		
Additional Reaction Control			
Propellant	15		
Command Module	(10,660)	10,660	
Basic NAA CM	10,156		
Add Self Maneuvering Unit (1)	115		
Add Docking & Airlock Penalty	389		
SPACECRAFT at Earth Launch Site		83,265	
Adapter		-3,230	
Translunar		80,035	
Mid-Course Correction & Lunar Orbit			
Establishment - Propel. Consumed		-23,000	
Lunar Orbit - CM + SM and LEM		57,035	
CM + SM		27,745	
LEM			29,290
Transfer from CM to LEM			
Crew		-380	380
Pressure Suits		-60	60
Environment Control Backpacks (2)		-60	60
Self-Maneuvering Unit (1)		-115	115
Cine Camera - Instrumentation (2)		-20	20
CM & SM after Transfer		27,110	
LEM after transfer			29,925
Separate . Reaction Control Propellant			-31
Begin Lunar Landing Maneuver			29,894
Descent Propellant Consumed			-14,620
Propellant Consumed - Reaction Cont. Sys.			-82
Coolant Water Consumed (from Environ-mental Control System)			-30
Propellant Consumed (from Electrical Power System)			-5
Lunar Landed			15,157
Landing Antenna			-15
Consumed & Off-Loaded (from Environmental Cont. Syst.)			-106
Fuel Cells			-533

(TABLE 17-II cont.)

Transceiver VHF, Man-To-LEM		-4
Omni Antenna VHF, Man-To-Lem		-1
Erectable Antenna 2295 mc		-15
Real Time TV Camera		-10
Cine Camera	(1)	-10
Film Developing Unit		-5
Scientific Payload		-135
Food		-4
Landing Gear		-975
Descent Tanks & Supports		-338
Descent Pressurization		-744
Descent Reserve except 242 lbs. for Launch Reserve		-1220
Lunar Launch		11,042
Ascent Propellant Consumed		-4,842
Propellant Consumed - Reaction Cont. Syst.		-63
Coolant water & oxygen consumed Environmental Cont. Sys.		-32
LEM in Lunar Orbit		6,105
CM + SM in Lunar Orbit	27,110	
Rendezvous - Propel. Consumed, Main/RCS	-537	-127
At Docking, CM+SM;LEM RCS for Docking	26,573	-6
At Docking, LEM		5,972
Transfer from LEM to CM		
Crew	380	-380
Pressure Suits	60	-60
ECS Backpacks (2)	60	-60
SMU (1)	115	-115
Waste Water & Tankage ECS	23	-23
Photos & Container	6	-6
Scientific Payload	80	-80
LEM Left in Lunar Orbit		5,248
CM + SM Prior to Escape from Lunar Orbit	27,297	
Lunar Orbit Escape & Transearth		
Mid-course correction	-7,867	
Transearth CM + SM	19,430	

*SM   Service Module
ref. - letter of 6 April 1962 from Mr. W. F. Rector, III
NASA, to Mr. J. S. Buchan, LTV

CM   Command Module
same ref. as SM; gives weight of CM as 8125 lbs.
adding 25% for growth allowance gives 10,156 lbs.

NAA   North American Aviation
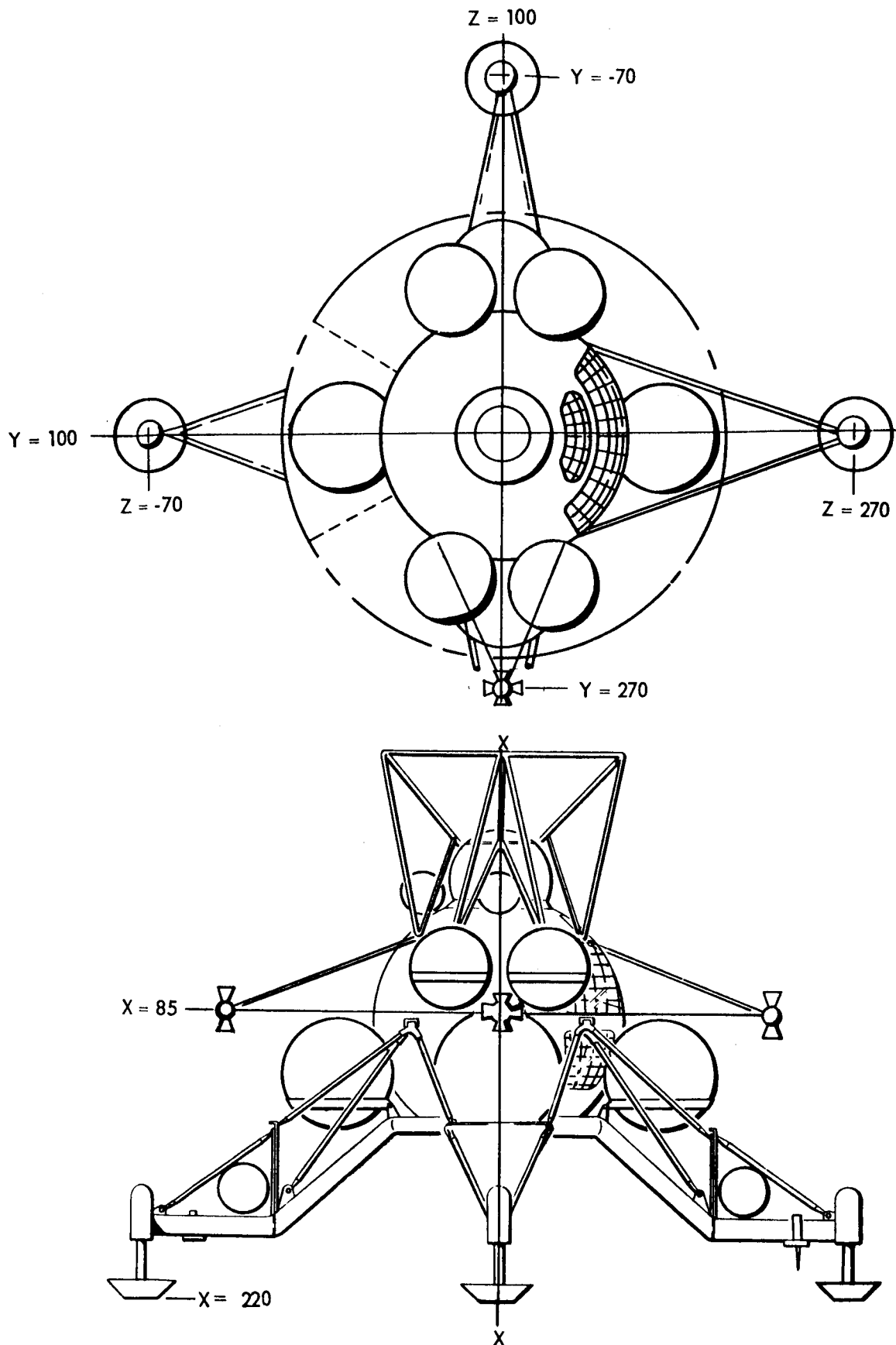
Figure 17-3 AXIS REFERENCE SYSTEM

TABLE 17-III

WEIGHT, BALANCE, AND MOMENT OF INERTIA SUMMARY

Event	Weight	C.G. Station			Moment of Inertia Slug-Ft^2			Product of Inertia Slug-Ft^2		
	Lbs.	X	Y	Z	I_{xx}	I_{yy}	I_{zz}	P_{xz}	P_{xy}	P_{yz}
LEM docked to CM just prior to separation	29,925	100.8	100.5	99.0	33,217	17,015	29,518	2	104	1,713
Lunar landed	15,157	88.8	100.9	98.2	12,199	8,309	14,008	81	143	1,726
Lunar launch - without landing gear and staged propulsion	11,042	72.1	99.6	98.6	7,981	3,666	8,881	105	108	1,775
LEM docked to CM prior to transfer of crew back to CM - end of mission	5,972	83.7	98.5	97.9	2,320	2,508	3,280	61	53	1,788

17.2   DETAIL WEIGHT BREAKDOWN

The reporting format established by NASA for the Apollo effort has been used for presenting the weight breakdown of the HS-625 vehicle. This section is divided into three parts:

(a) Crew Station
(b) Propulsion
(c) Landing System

Weights are divided by item, group, section and division, giving a very clear distribution of the weight. Descriptive data for each group is shown in the Weight Justification section and in the respective sections in other volumes of the report.

17.2.1

	WEIGHT — POUNDS		
	Detail	Group	Consumed
CREW STATION		5027.0	
Structure		(987.0)	
Body	(883.0)		
Shell	76.0		
Upper Band	10.8		
Floor	31.2		
Insulation & Thermal Coating	9.1		
Weld Lines, Fittings, Joints	19.9		
Equipment Attaching Hard Points	192.0		
Window Installation	198.0		
Internal Truss	346.0		
Engine Support	(52.0)		
"Spokes"	13.3		
Intersection Ring and Welds	6.0		
Gimbal Attach Fitting	7.7		
Web	25.0		
Airlock	(52.0)		
Shell	12.6		
Doors	3.6		
Handles & Latching Mech.	3.0		
Cross Frames	1.4		
Rings	18.8		
Seals & Collapsible Sect.	10.2		
Misc. Hand Holds, Steps, Hdwe.	2.6		
Air Distribution System & Circuitry System for Translunar incl. in ECS & Elect. Power System			
Systems		(2913.8)	
Navigation & Guidance		262..0	
Composite Rendezvous & Landing Radar			
Electronics	33.0		
Antennas	23.0		

	WEIGHT — POUNDS		
	Detail	Group	Consumed
Tracking & Computing Syst.			
Beacon	5.0		
Computer (includes computer function of ESS) (2)	47.0		
Optical Tracker	20.0		
Manual Telescope (Backup for Optical Tracker)	15.0		
Inertial Measuring Unit	45.0		
Body Mounted Accelerometer (1)	5.0		
Horizon Scanner System	10.0		
Cooperative Radio Recvr.	25.0		
Circuitry	30.0		
Installation	4.0		
Automatic Control & Stabil.		33.0	
Gyros (Roll, Pitch, Yaw)	3.6		
Dead Band Amplifier (3)	3.0		
Pulse Generator & Cont. (6)	6.0		
Autopilot--Gimbal Logic (3)	4.5		
Differentiators (9)	6.7		
Summing Amplifier (3)	1.5		
Switching Modules (3)	1.5		
Circuitry	5.2		
Installation	1.0		
Reaction Controls		492.0	
Rocket Chambers, Solenoid Valves, Filters			
Roll - 50 lb. thrust (4)	14.8		
Pitch - 100 lb. thrust (4)	23.0		
Yaw - 100 lb. thrust (4)	23.0		
Rendezvous - 200 lb thrust (4)	30.0		
Tanks			
Helium-Pressurization	7.6		
Fuel	4.5		
Oxidizer	5.4		
Helium	0.6		
Fuel (Aerozine 50)	115.3		103.0
Oxidizer (N_2O_4)	230.8		206.0
Pressure Regulator (2)	2.0		
Valves			
Check (4)	2.0		
Squib-Actuated, N/O (38)	6.1		
Squib-Actuated, N/C (5)	0.8		
Relief (2)	1.0		

	WEIGHT — POUNDS		
	Detail	Group	Consumed
Filters - Propel. Line (2)	2.0		
Bladders (2)	3.0		
Burst Diaphragms (4)	2.0		
Circuitry	4.9		
Plumbing (Lines & Fittings)	13.2		
Environmental Control System		503.8	
Suit Circuit	(70.9)		
Suit Diverter Valve (2)	4.8		
Debris & Vomit Trap (2)	2.4		
Suit Check Valve	0.6		
Suit Circuit Relief Valve	1.1		
Diverter Valve, Barometric	1.1		
Emergency Shut-off Valve	1.6		
Cabin Press. Control Valve	1.6		
Suit Circuit Check Valve (4)	1.2		
Air Inlet Shut-off Valve	0.6		
Debris Trap	2.5		
Suit Circuit Compressor (2)	16.0		
Reg. Heat Exchanger (Part of Catalytic Burner)			
Catalytic Burner	2.0		
Li OH Bed Selector Valve (4)	2.4		
CO_2 & Odor Removal Canister (2-7)			
Li OH & Activated Char.	6.4		
Cannister	10.5		
Suit Circuit Heat Exchanger	6.0		
H_2O Separator Inlet Selector Valve	0.9		
H_2O Separator Outlet Select.	0.4		
H_2O Separator (2)	6.8		
Suit Temp. Control By-pass Valve	0.9		
Emergency O_2 Flow Valve	1.1		
Cabin Circuit	(33.5)		
Cabin Air Inlet Screen	0.8		
External Supply Inlet Valve	1.1		
Ext. Supply Return Valve	1.1		
Cabin Re-pressuriz. Valve	0.4		
Cabin Heat Control Valve	0.5		
Cabin Fans (2)	11.2		
Cabin Fan Check Valves (2)	1.0		
Cabin Heat Exchanger	5.1		
Cabin Temp. Control Valve	2.0		
Pressure Relief Shut-off Valve	1.1		
Airlock Valves (2)	4.2		
Pressure Relief Valve (7.5 psi)	5.0		

	WEIGHT — POUNDS		
	Detail	Group	Consumed
Thermal Loop	(132.2)		
Water Boiler	4.0		
Glycol	8.0		
Accumulator	3.2		
Accumulator Shut-off Valve	0.3		
Glycol Pump By-pass Valve	0.5		
Glycol Pump (3)	5.4		
Glycol Check Valve (7)	1.4		
Cold Plates	30.3		
Fluid - Cold Plates	34.3		
Emergency Cooling Valve	0.4		
Radiator By-pass Valve	0.5		
Circuit Selector Valve	0.5		
Glycol Modulating Valve (2)	2.2		
Regenerative Heat Exchanger	4.2		
Radiator Circuit Selector Valve	0.5		
Radiator	31.5		
Fuel Cell Heat Exchanger	5.0		
Water Loop	(79.5)		
Water Shut-off Valves (6)	1.8		
Water Cooling Heat Exchanger	2.0		
Water Flow Control Valve (2)	2.2		
Cooling Water Tank	8.8		
Cooling Water	53.3		47.3
Waste Water Tank	5.1		
Water Check Valves (3)	0.3		
Urine Ion Exchange Filter	6.0		
Oxygen Supply Loop	(101.0)		
Normal O_2 Storage Tank	30.0		
Normal Oxygen	50.0		33.3
Cryogenic Expulsion Heat Exchanger (2)	2.0		
O_2 Vent Valve	0.4		
O_2 Fill Valve	0.3		
Rendezvous Oxygen Tank	8.9		
Rendezvous Oxygen (Gaseous)	4.0		2.0
O_2 Tank Shut-off Valve	0.4		
O_2 Press. Reducer	0.9		
O_2 Check Valve	0.2		
Normal O_2 Shut-off Valve	0.4		
Backpack Fill Valve	0.3		
O_2 Pressure Reducer (2)	1.6		
O_2 Pressure Reducer (2)	1.6		

| | WEIGHT — POUNDS | | |
	Detail	Group	Consumed
Electrical Hardware	(21.7)		
Mechanical Hardware	(58.4)		
Airlock-Air Distribution System	(6.6)		
Ducts-Pressure & Return	4.0		
Connectors, Shut-off Valve, Hardware	2.0		
Zipper Installation	0.6		
Electrical Power		888.0	
Fuel Cell System	(538.0)		
Fuel Cells (3)			
Cell Module, Electrolyte, Case	270.0		
Controls	150.0		
Heat Exchanger (Glycol)(3)	6.0		
Oxygen	45.6		28.4
Hydrogen	5.7		3.6
Oxygen Tank (2)	14.0		
Hydrogen Tank (2)	11.4		
Valves			
Shut-off (14)	21.0		
Fill & Vent (4)	8.0		
Pressure Regulator (8)	6.0		
Battery System			
Batteries (2)	(200.0)		
Main Dist. System	(143.6)		
Airlock-Power Distribution	(6.4)		
Wire Bundle	6.2		
Plug & Hardware	0.2		
Communications		128.4	
VHF Transceiver Man-to-LEM	3.8		
243 mc Transceiver LEM-to-Lunar Orbiting Vehicle	22.3		
2295 mc Transmitter Moon-to-Earth	23.8		
2215 mc Receiver Earth-to-LEM	9.2		
VHF Omni Antenna Man-to-LEM	0.8		
243 mc Omni Antenna LEM-to-Lunar Orbiting Vehicle	1.5		
2295 mc Antenna (4 ft. dia.)	15.0		
Control Unit - 2295 mc Antenna	5.0		
2295 mc Erectable Antenna (12 ft. dia.)	15.0		
Circuitry	28.8		
Installation	3.2		

	WEIGHT — POUNDS		
	Detail	Group	Consumed
Instrumentation		78.0	
PCM System	(22.5)		
Signal Conditioners (20)	2.0		
Commutators (15 Gate Mod.) (4)	1.0		
Analog to Digital Converter (2)	6.0		
Buffer	2.0		
Output Gates (15 Gate Mod.)(5)	1.5		
Oscillator and Clock (2)	4.0		
Programmer (2)	6.0		
Calibrator & Power Supply (2)	4.0		
Real Time T.V. Camera	10.0		
Cine Camera (Trans. from CM) (2)			
Film Storage Container (8)	6.4		
Transducers (50)	10.0		
Film Developing Unit	5.0		
Circuitry	18.5		
Installation	1.6		
Scientific Payload (NASA suggested breakdown)		215.0	
Radioactivity	10.0		
Temperature	6.0		
Surface Detail Composition	15.0		
Rock Survey	1.0		
Communications	10.0		
Soil Analysis	10.0		
Friction	4.0		
Density Survey	5.0		
Core Sample	25.0		
Seismograph	40.0		
Atmosphere	27.0		
Gravity	5.0		
Magnetic Field	7.0		
Samples Container	10.0		
Records and Photos	20.0		
Film Process.	10.0		
Camera	10.0		
Samples (50 lbs to be collected on moon)			
Installation (included with main structural supports)			
Displays and Controls		141.0	
Attitude Controller (3-axis)(2)	8.0		
Thrust Controller (2)	3.46		
Landing Gear			
Extend Handle	3.0		
Position Indicator (4)	.56		

	WEIGHT — POUNDS		
	Detail	Group	Consumed
Abort			
Abort Handle (2)	6.0		
Lunar Launch			
Landing Gear Rel. Switch	.25		
Gear Release Lights (4)	.56		
Start Countdown Switch	.13		
Ignite Switch	.13		
Stop Countdown Switch	.13		
Lighting			
Displays Control ⎫			
Exterior Control ⎬	4.0		
Interior Control ⎭			
Navigation, Guidance, Stab., and Control			
Attitude Display (2)	15.0		
Auto. Stab. Caution Lights (in master caution system) (3)			
Longitudinal Distance (2)	2.0		
Longitudinal Velocity (2)	2.0		
Lateral Distance (2)	2.0		
Lateral Velocity (2)	2.0		
Altitude (2)	2.8		
Vertical Velocity (2)	2.0		
In-plane Line of Sight Angle (2)	2.0		
Rate of Change of In-plane Line of Sight Angle (2)	2.0		
Out of Plane Line of Sight Angle (2)	2.0		
R. O. C. of Out of Plane Line of Sight Angle (2)	2.0		
Normal Acceleration (2)	1.68		
Computer Control Panel			
Time ⎫			
Time to Go ⎪			
Action Switch/Light (4) ⎪			
Mode Switch/Light (4) ⎪			
On-Off Switch ⎬	14.0		
Function Light ⎪			
Readout Window ⎪			
Keyboard ⎭			
Autopilot Panel			
Autopilot Switch	.13		
Pitch Control Switch	.13		
Roll Contr. Switch	.13		
Yaw Contr. Switch	.13		
Control Mode	.13		

	WEIGHT — POUNDS		
	Detail	Group	Consumed
Electrical Power			
Voltage (3)	} 10.0		
Circuit Breakers (15)			
Ampere (3)			
N$_2$ Survey Switch	.13		
Flow Rate Survey	.13		
Flow Rate Indicator	.51		
Flow Switches (7)	2.73		
N$_2$ Pressure Ind.	.51		
Caution Lts. (9)	.60		
Communications			
Power Sw. (3 position)	.13		
"A" Trans. Switch (3 position)	.13		
Mike Switch	.13		
"B" Trans. Switch (3 position)	.13		
Mode Switch	.13		
"C" Trans. Switch (3 position)	.13		
Instrumentation			
Power Sw. (3 position)	.13		
T. V. Camera Switch	.13		
Cine Cam. Sw.	.13		
Environment Control System			
Caution Lights (in master caution system) (10)			
CO$_2$ Partial Press. Indicator	.51		
Cabin and Suit Pressure	.51		
Tank Quantity	.51		
Tank Pressure	.51		
Tank Temperature	.51		
Glycol Quant.	.52		
Glycol Temp. Indicator	.51		
Cooling H$_2$O Level	.52		
Cabin and Suit Temp.	.51		
Glycol Valve Selector	.13		
Emergency-Equip. Cooling Sw.	.13		
Suit Compressor Selector (3 position)	.13		
Cabin Fan Sel. (3 position)	.13		
Glycol Pump Sel. (3 position)	.13		
Cabin Temp. Cont.	.13		
Cabin Dump Switch	.13		
Suit Temp. Cont.	.25		
Loop Temp. Switch	.13		
Oxygen Press. Switch	.13		
Tank Survey Switch	.13		
Radiator Loop Sel. (3 position)	.13		
Suit Air Flow (Knob) (2)	.20		
Catalytic Burner Switch	.13		
Rendezvous Oxygen Handle	.10		
Suit Circuit Handle	.10		
Air Inlet Handle	.10		

	WEIGHT – POUNDS		
	Detail	Group	Consumed
Reaction Control System			
Helium Pressure Indicator	.51		
Temperature Indicator	.51		
Quant. Indicator	.52		
Pressure Indicator	.51		
Tank Survey Switch	.13		
Pressurize Sys. Sw. 3 position	.13		
Nozzle Isolation switch	.13		
Nozzle Isolation Sel. 16 posit.	.25		
Sys. Caut. Light (in master			
control system (1)			
Propulsion System			
Chamber Pressure (3)	1.53		
Helium Pressure	.51		
Fuel & Oxidizer Pressure	.51		
Helium, Fuel & Oxidizer Temp.	.51		
Tank Survey Switch (12 position)	.25		
Fuel – Ox. Quantity	.52		
Launch Tank Pressure Switch	.13		
Landing Tank Pressure Switch	.13		
System Arm Switch	.13		
Nozzle Isolate Sw. (3 pos.) (3)	.32		
Start (push)	.13		
Stop (push)	.13		
ΔV Obtained Indicator	.51		
Throttle Mode Switch	.25		
System Drain Switch	.13		
Nozzle Inoperative Warning Lt.	.09		
Tank Out-of-Limit (Pressure or			
Temp.) Warning Light	.09		
Master Caution Light	.16		
Caution Panel	1.25		
Circuitry	8.0		
Structure	22.0		
Crew Support		46.5	
Crew - 95th Percentile (2)			
(Transferred from Command			
Module, 380 lbs.)			
Pressure Suits (2)			
(Transferred from Command			
Module, 60 lbs.)			
Water			
Drink⎱ (included in ECS)			
Wash ⎰			
Food (1 day; volume 7 days)	3.6		
Self-Maneuvering Unit			
(Transferred from Command			
Module, 115 lbs.)			

	WEIGHT — POUNDS		
	Detail	Group	Consumed
Furnishings			
First Aid	1.9		
Personal	1.0		
Extra Pressuire Suit Under-garment - Volume only			
Toothbrush and Paste - Volume only			
Sanitation - Volume only			
Shave - Volume only			
Deodorant - Volume only			
ECS Backpacks (2) (Transferred from Command Module, 60 lbs.)			
Seat, Restraint, Vision Adjust. (2)	(40.0)		
Screen Wire for Seat Back and Pan	1.4		
Tubular Supports for Fixed Seat	18.6		
Brazing, Local Gussets and End Fittings	4.0		
Adjustment Provisions	6.0		
Restraint Provisions	10.0		
Retrieval and Docking		100.0	
Frame			
Tube 1 (4)	39.6		
2 (8)	45.2		
3 (8)	7.0		
Miscellaneous	8.2		
Electronic Support System		26.0	
Built-in Test Equipment	18.0		
Computer (incl. in Nav. & Guid. computers)			
Input/Output Data Handling	8.0		
Display & Control (incl. in Main Display Board)			
Growth Allowance (25% of 4505 lbs., the weight of the Crew Station structure and systems at the time of separation from the spacecraft just prior to the descent maneuver)		(1126.2)	

17.2.2

PROPULSION

	WEIGHT — POUNDS		
	Detail	Group	Consumed
PROPULSION		23,288.0	
Inert		2,122.0	
Engines (Thrust Chambers + Eng. Mtd. Access.) (3)	360.0		
Gimbal and Truss	25.0		
Gimbal Actuation	84.0		
Lines, Fittings, Valves	110.0		
Tanks and Supports			
Ascent			
Fuel (2)	62.0		
Oxidizer (2)	82.0		
Descent			
Fuel (2)	146.0		
Oxidizer (2)	192.0		
Pressurization Systems			
Ascent			
Tank to pressurize fuel	122.5		
to pressurize oxidizer	174.5		
Helium Pressurant			
to pressurize fuel	8.9		
to pressurize oxidizer	11.1		
Descent			
Tank			
to pressurize fuel	308.9		
to pressurize oxidizer	387.5		
Helium Pressurant			
to pressurize fuel	21.2		
to pressurize oxidizer	26.4		
Propellant		21,166.0	
Consumed			
Ascent			4,842.0
Fuel	1614.0		
Oxidizer	3228.0		
Descent			14,620.0
Fuel	4873.0		
Oxidizer	9747.0		
Reserve			
Ascent			
Fuel	81.0		
Oxidizer	161.0		
Plus 242 lbs. of Descent reserve not off-loaded prior to launch.			
Descent			
Fuel	487.0		
Oxidizer	975.0		

17.2.3	WEIGHT		POUNDS
	Detail	Group	Consumed
LANDING SYSTEM		975.0	
Member No. 1* (4)	96.0		
Member Nos. 2, 3 (8)	149.2		
Member Nos. 4, 5 (8)	64.8		
Member Nos. 6, 7 (16)	23.0		
Member No. 8 (8)	10.8		
Member Nos. 9, 10 (8)	67.2		
Member No. 11 (4)	78.4		
Web (8)	32.0		
Feet			
Shaft (4)	66.4		
Piston (4)	8.0		
Cylinder Cap (4)	13.6		
Pad (4)	142.4		
Cylinder (4)	68.0		
Trunnion (4)	24.0		
Support Tube	80.0		
Release Mechanism	40.0		
Miscellaneous Hardware	11.2		
LEM - Total Weight on the Pad	29,290.0		

*See descriptive sketch in Weight Justification - Section 17.3.5

17.3   WEIGHT JUSTIFICATION

The establishment of a realistic weight estimate for the Lunar Excursion Module was one of the prime study requirements. The objective of this section is to prove the authenticity of the weight of the LEM.

17.3.1   There are several basic methods used to accomplish this purpose.

(a) Semi-Analytical

The basic or optimum weight is determined on a theoretical basis. This weight is then statistically adjusted for the non-optimum weight by including all factors affecting the final installed weight.

(b) Statistical

An accumulation of categorized statistics on all available and pertinent data is screened for association with the present design. The item weight selected is then adjusted based on specific design considerations.

(c) Calculations From Drawings

Weight calculations are based on layout drawings and engineering sketches that have been drawn in sufficient detail and analyzed to allow actual sizing of parts.

(d) Vendor Data

Weight inputs are requested from various vendors who are all bound to the same specification. Past contractor experience with vendors regarding actual performance is invaluable here, for it is a guide as to the degree of adjustment necessary to put the vendor's original estimate in perspective with the final, delivered weight of the item.

The weights developed for the HS-625 vehicle were justified on the basis of a combination of the above methods. Since statistical data are lacking on vehicles similar to the one proposed, it follows that detail calculation of the structural components is the best way to show the origin and reasons for the structural weights presented. Vendor inputs were requested and received on equipment items for the systems in the HS-625 vehicle. The vendors were made aware of the desire for lightweight designs, but at the same time it was clearly stated that they would have to justify the weight data proposed. This requirement placed a constraint on the vendors and resulted in the presentation of more realistic weight data to NASA. Mercury and Apollo weight data have been used whenever applicable data were available.

17.3.2 Structure - Crew Station

SUMMARY OF WEIGHTS ANALYZED

CREW STATION STRUCTURAL WEIGHT	987.0 lbs.
Body	883.0
Engine Support	52.0
Airlock	52.0
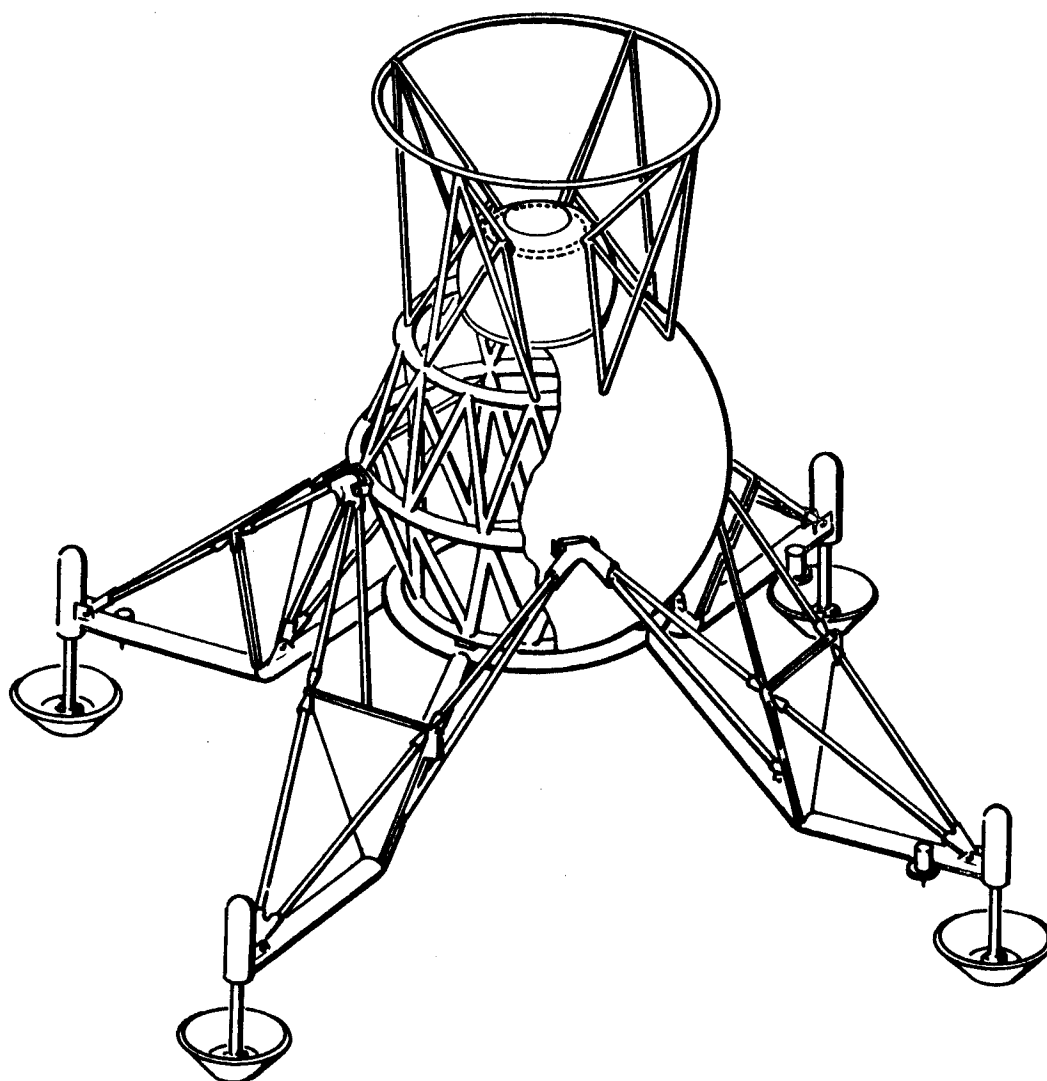
17.3.2.1 Body

The shell is a spherical pressure vessel of welded aluminum construction. The primary load carrying structure is an aluminum internal truss which extends from the docking arms to the landing gear support points. All loads are carried through the truss except pressurization loads which are confined to the spherical shell. Equipment and tank attachment points are located at various stations along the truss work.

Tension-loaded frames are required at the intersection joints of the airlock and floor with the spherical shell. The floor, an aluminum sheet with non-slip grid work, rests against the support truss and is used for redistributing internal pressurization loads to the support truss. A lightweight multi-layer radiation shield covers the metal exterior of the command capsule and provides considerable heat blockage to the inner command capsule.

The weight calculations presented on the following pages are based on structural analyses and are intended to show the origin of the structural weights used. Aircraft and spacecraft structural weight penalties (for doors, frames, cutouts, seals, production joints and splices) were used to develop the final design weights.

BODY (including windows and internal truss from separate sheets)	883 lbs.
Shell 38,016 in^2 x .02 in. x .1 lbs/in^3	76.0
Upper Band .704 in^2 x 3.14 x 48.9 in. x .1	10.8
Floor 38 ft^2 x .821 lbs/ft^2	31.2
Insulation and Thermal Coating 220 ft^2 x .1 in. (effective) x $\dfrac{ft.}{12\ in.}$ x $\dfrac{5\ lbs.}{ft^3}$	9.1
Weld Lines, Fittings, Joints (6% of truss weight)	19.9
Equipment Attaching Hard Points *	192.0
Window Installation (see separate page for details)	198.0
Internal Truss (see separate page for details)	346.0
* Weight allowance for local beef-up of structure, plus main mounting shelves and panels is 10% of the weight to be supported. Additional hardware is logged with individual system estimates.	

INTERNAL TRUSS 346 lbs.
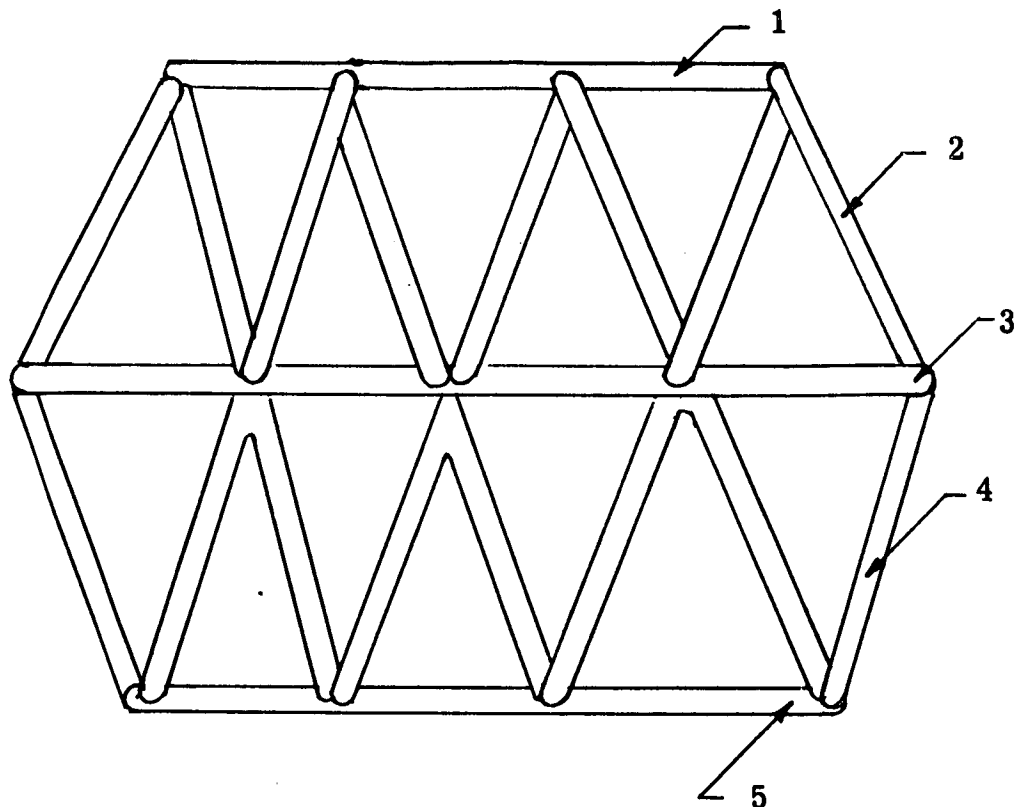
| Tube No.	Aluminum		Length In.	Lbs/In.	Reqd.	Lbs.
1	⊕	5 x .120	267	.183	1	50.7
2	⊙	2 x .049	39.5	.030	24	28.4
3	▣	4 x 4	377	.361	1	136.0
4	⊙	3 x .109	42.5	.098	24	100.0
5	⊙	4 x .109	235	.132	1	31.0

Window Installation

A design has been provided to carry hoop tension loads in the sphere, across the glass area, by structural continuity members 0.2 inches thick by 0.4 inches deep. These structural members are arranged in great circle pattern forming an approximately 4 inch matrix over the entire vision area. The glass is sealed around the periphery with flexible seals. Protection against micrometeorites and abrasion is designed into the window; an external transparent coating is applied for thermal control.

TYPICAL CROSS-SECTION

Retaining Clip

Glass

Grille Frame

Retainer

Bonded Edging
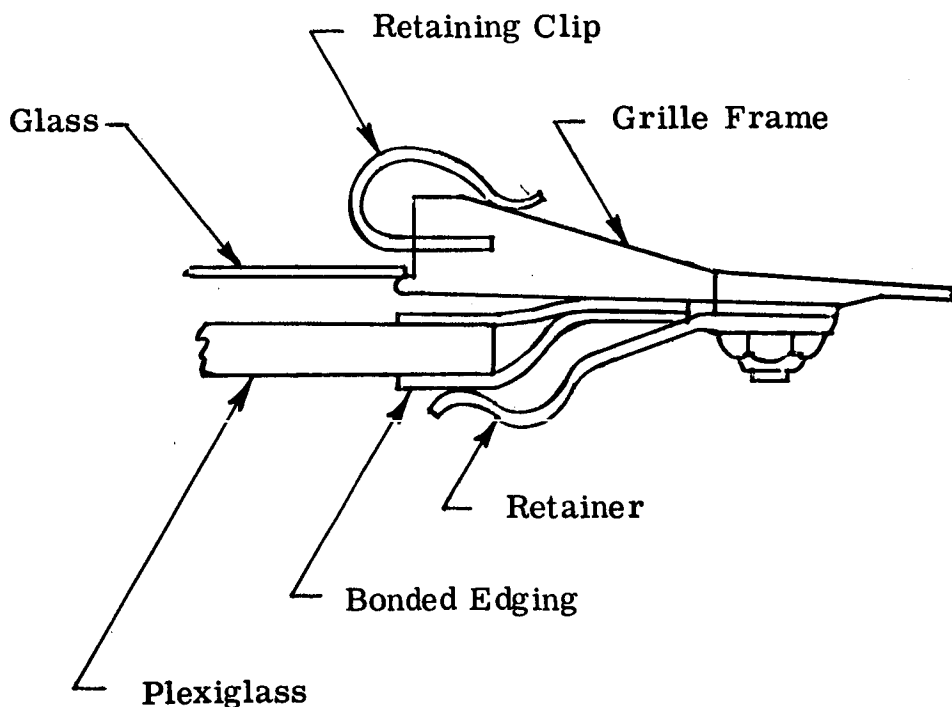
Plexiglass

WINDOW INSTALLATION   198 lbs.

1. Upward vision
2. Forward vision
3. Downward – right vision
4. Downward – left vision
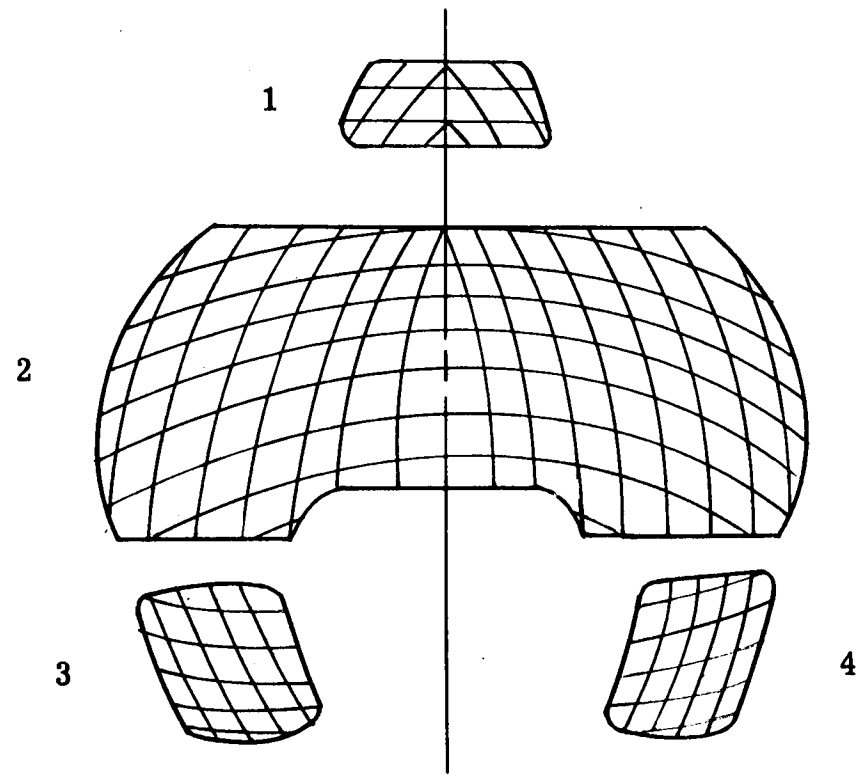
	Area	Inside Plexiglass				Outside Glass				Frame & Hdw.		
		t	Vol	ρ	Wt.	t	Vol	ρ	Wt.	Unit Wt	Wt.	
	sq in	in.	in^3	lbs/in^3	lbs.	in.	in^3	lbs/in^3	lbs.	lbs/in^2	lbs.	lbs.
1.	431	.30	129	.048	6.20	.03	12.9	.086	1.11	.0116	5.02	12.33
2.	4050		1215		58.30		121.5		10.45		46.95	115.70
3.	1166		350		16.80		35.0		3.01		13.50	33.31
4.	1166	.30	350	.048	16.80	.03	35.0	.086	3.01	.0116	13.50	33.31
TOTALS					98.10				17.58		78.97	194.65

Window Shades 8640 sq. in. x .005 in. x .0531 $\frac{lbs.}{in.^3}$ + Hdw.	3.30

17.3.2.2   Engine Support

The engine support truss is located below the Crew Station floor and is constructed of aluminum tubing. The tubes form radial spokes that extend outward from the gimbal point to the shell truss.

In this arrangement the support truss serves two purposes:

(a) Engine thrust redistribution to the truss.
(b) Stabilization of the   Crew Station   floor against compression buckling from internal pressurization.

ENGINE SUPPORT	52 lbs.
1. Aluminum "spoke" tubes - $1^5/_8$ x .049 in. = .0245 lbs/in. .0245 x 45 in. x 12 required =	13.25
2. Intersection Ring and Welds	6.00
3. Gimbal Attach Fitting	7.75
4. Web .040 in. x 6250 in^2 x .1 lbs/in^3	25.0

Ties into internal truss of the body around the periphery.

Spokes

Web

Ring

Gimbal Attach Fitting
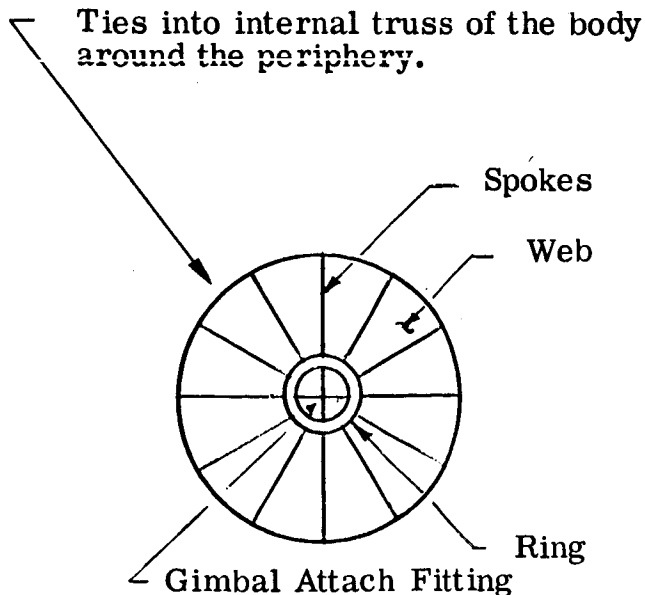
17.3.2.3 Airlock

The airlock consists of a spherical shaped aluminum pressure vessel with hatches provided at each end. The ingress and egress hatches are aluminum skin with cross frames for support necessitated by crew loadings during airlock operation. Pressure sealing is provided for each hatch in the locked position. Ladder type rungs are provided in the airlock to facilitate crew entrance and exit.

AIRLOCK - CREW STATION	52 lbs.
Shell 43.6 ft^2 x $\frac{144 \text{ in}^2}{\text{ft}^2}$ x .020 in. x .1 $\frac{\text{lbs.}}{\text{in}^3}$	12.6
Door 6.1 ft^2 x .020 in. x $\frac{144 \text{ in}^2}{\text{ft}^2}$ x .1 = 1.8 x 2	3.6
Handles and Latching Mech.	3.0
Cross Frames .1 sq. in. x 35 in. x .1 lbs/in^3 = .35 x 4	1.4
Rings .5 sq. in. x 94.1 in. x .1 lbs/in^3 = 4.7 x 4	18.8
Seals and Collapsible Section	10.2
Misc. Hand Holds, Steps, Hardware	2.6
Air Distribution System and Circuitry System for Translunar included in: (a) Environmental Control System Section 17.3.3.5 Wt. = 6.6 lbs. (b) Electrical Power System Section 17.3.3.6 Wt. = 6.4 lbs.	

50 in.

Cross Frames

Rings

Shell

Doors
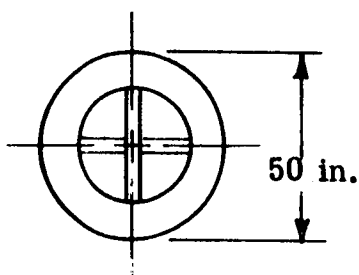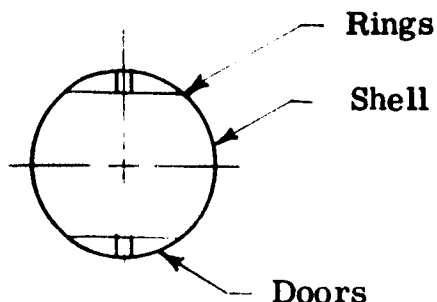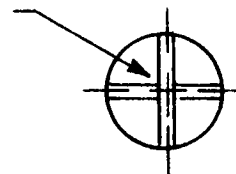
AIRLOCK - PENALTY TO COMMAND MODULE	36.5 Lbs.
Environmental Control - Air Distribution System	(6.0)
Ducts - Pressure and Return	4.0
Connectors, Shut-Off Valve, Hardware	2.0
Electrical Power - Power Distribution	(6.4)
Wire Bundle, 100 wires	6.2
Receptacle and Hardware	0.2
Collapsible Section - Structure	(18.1)
Mylar $8430 \text{ in}^2 \times .015 \text{ in.} \times .05 \frac{\text{lbs.}}{\text{in}^3}$	6.3
Zipper Installation	0.6
Seals Over Zipper Installation	9.2
Hardware	2.0
Miscellaneous 20%	(6.0)

17.3.3   Systems - Crew Station

Justification of the weight of each system is presented in this section. The weights shown for each system are listed by component or subsystem. Detail weights for each system are presented in Section 17.2, the Detail Weight Breakdown.

Since there are certain general items common to most systems, weight justification for these items is discussed below, rather than repeating it for each system.

Circuitry is the term used to include wiring, connectors, plugs, receptacles, potting and hardware. A cross-section of data collected shows the following circuitry weight as a percent of systems weight:

Source	Per Cent
C-82A	9.9
F8U-2N	10.5
F94-C	18.1
AJ-1	19.8
Mercury	20.7
WF-2	21.6
Apollo	22.6
F8U-3	23.0

An average of 20% was used for circuitry in the HS-625 systems. This percentage is a function of the proximity of system components to each other and to the central distribution point.

Installation is the term used to include minor panels and hardware to attach equipment to the structure. The main supports and hardware are included in the body structural weight.

Based on the following comparison, an average allowance of 4% was used for the HS-625 vehicle.

Source	Percent of System Weight Installed
P3V-1	1.1
F8U-2	1.6
F8U-2N	1.7
Mercury	4.0
F8U-3	4.0
F94-C	5.1

The names of vendors whose data were used in this section have been purposely omitted for reasons of protocol. However, such information is available to the NASA upon request.

17.3.3.1   Navigation and Guidance

Summary of weights justified:

Navigation and Guidance System	262.0 lbs.
Composite Radar System	56.0
Tracking and Computing System	172.0
Circuitry and Installation	34.0

The navigation and guidance system, although basically automatic, also incorporates backup modes for redundancy and crew participation. The central sensor of the navigation system is the inertial measuring unit. Attitude and acceleration changes measured by this unit are fed into the central intelligence section of the guidance system, the digital computer.

A statistical approach is used to justify the navigation and guidance equipment items. Data received from various vendors were tabulated and plotted to show weight trends. Although the internal arrangement of a piece of gear varies from one vendor to another, each will perform the functions specified. It is therefore accurate to compare the unit weights on this common basis.

Composite Radar System

SELECTED WEIGHT = 56.0 LBS.
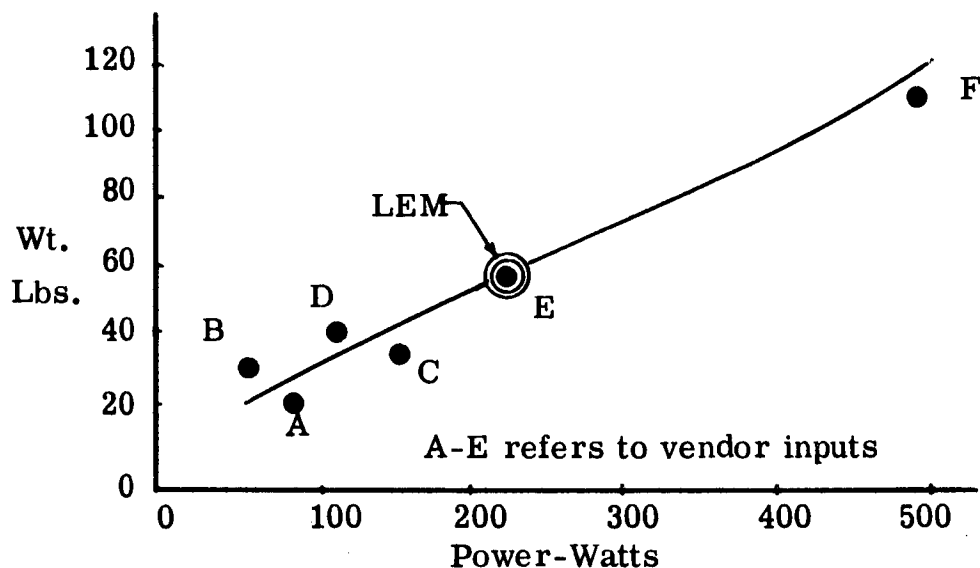
Based on an analytical study of vendor data, the technical and functional characteristics of the system selected are considered superior to the other systems while being competitive from a weight versus power standpoint.

Tracking and Computing System

Beacon	5.0
Cooperative Radio Receiver	25.0
Computer	47.0
Inertial Measurement Unit	45.0
Horizon Scanner	10.0
Optical Tracker	20.0
Manual Telescope	15.0
Body Mounted Accelerometer	5.0
	172.0 lbs.

● Beacon   Selected Weight = 5.0 lbs.
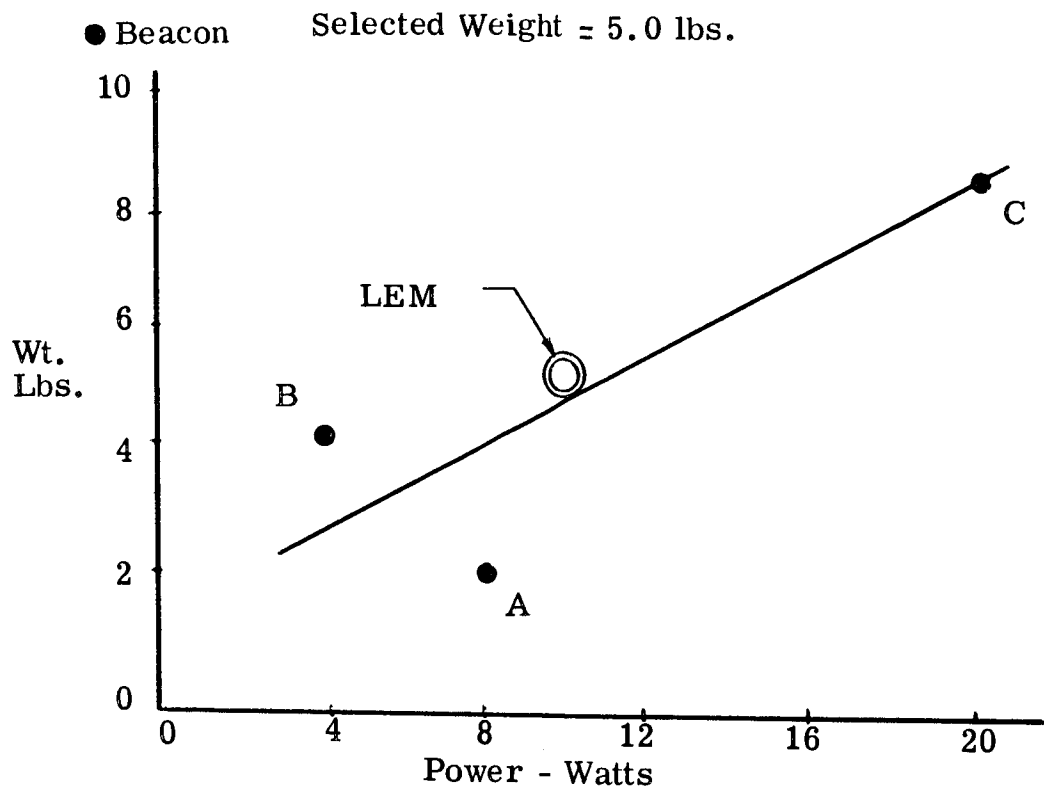
● Cooperative Radio Receiver

Selected Weight = 25.0 lbs.

At the suggestion of NASA, a moon Instrument Landing System
is included in the LEM Navigation and Guidance system. Presently, several
Instrument Landing Systems are being considered. It is felt that the weight
selected may be optimistic in view of present day, commercial Tacan, Loran,
etc. systems of approximately 100 pounds. Since this receiver will be used
in Apollo, it is expected that significant weight reductions will be made be-
fore acceptance of a unit for Apollo; and by the same reasoning, for the LEM.

● Computer

Selected Weight of Redundant Computers (2) = 47.0 lbs.
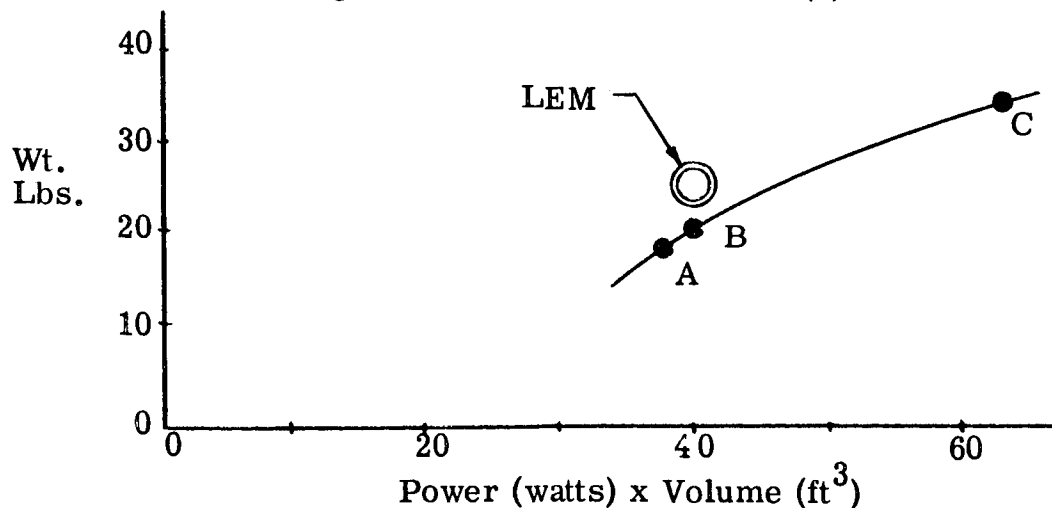
The computer selected is basically similar to Computer B except that additional weight has been added for incorporating the functions of the Electronic Support system.
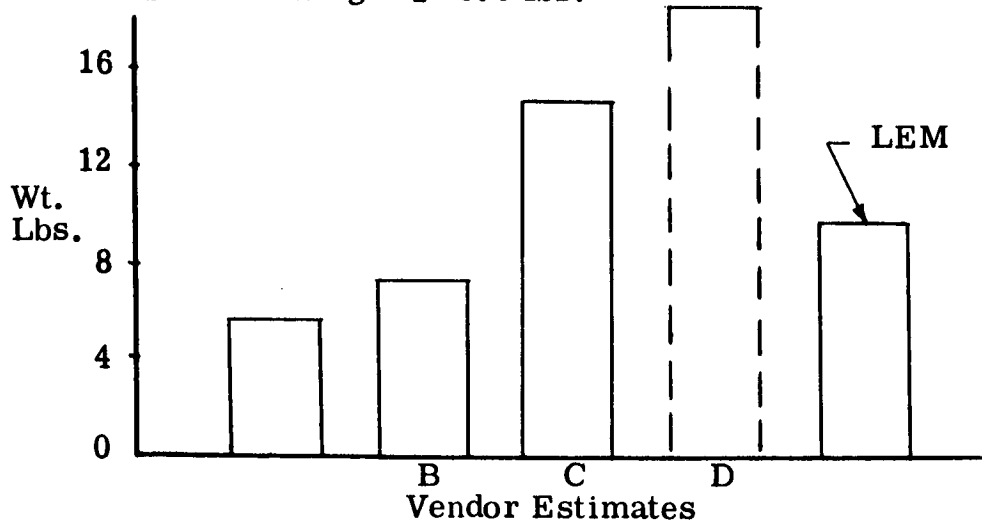
- Inertial Measurement Unit

Selected Weight = 45.0 lbs.
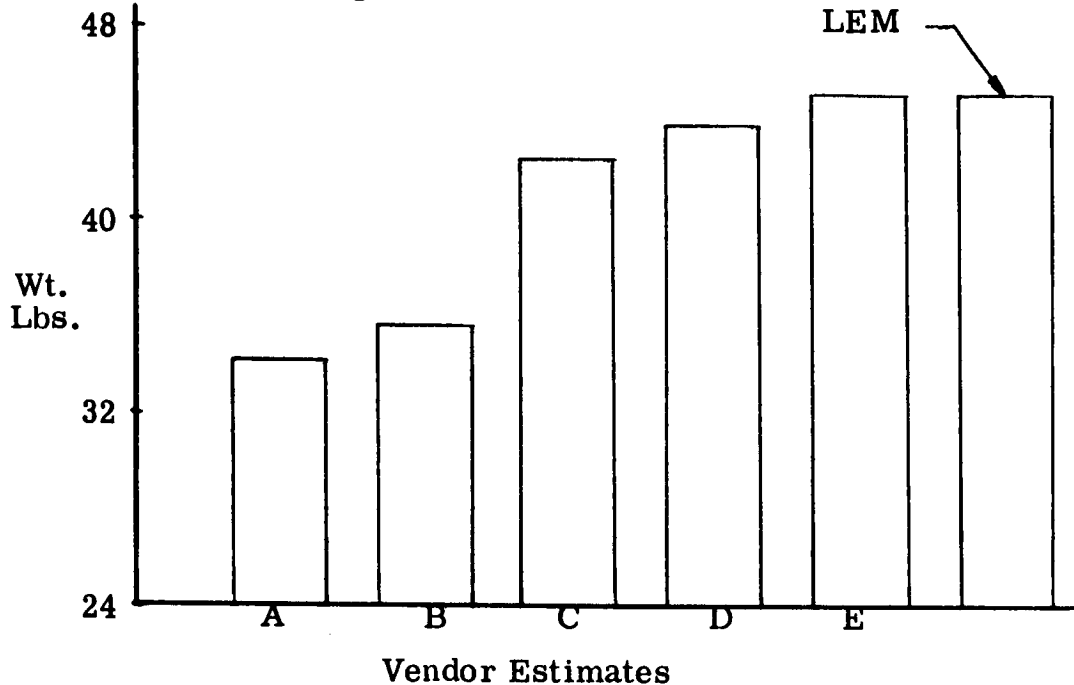
Vendor Estimates

- Horizon Scanner System
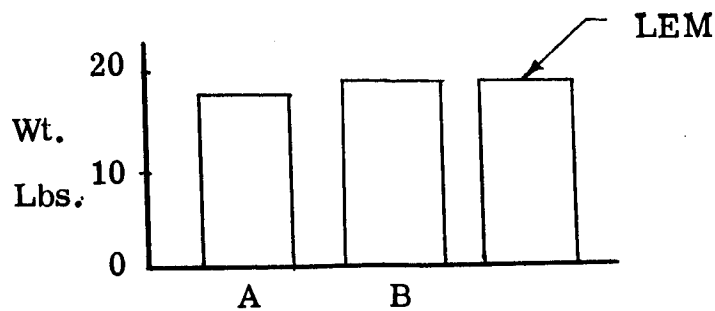
Selected Weight = 10.0 lbs.

Vendor Estimates

Vendor D's scanner measures direction of local vertical as well as distance from target. Based on past experience, Vendor C's delivered unit will weigh less than his preliminary estimate.

- **Optical Tracker**

    Selected Weight = 20.0 lbs.
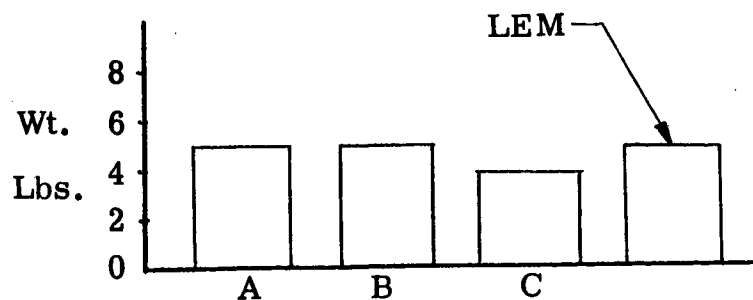

VENDOR ESTIMATES

- **Manual Telescope**

    Selected Weight = 15.0 lbs.
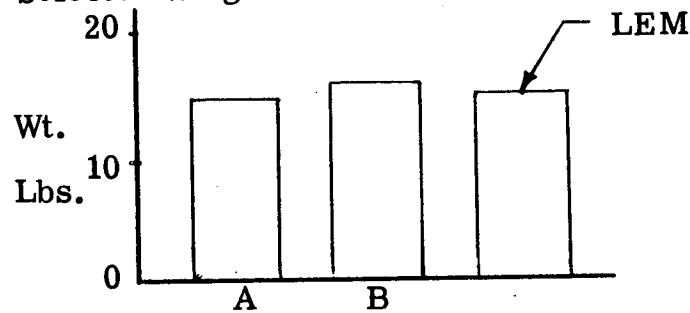
VENDOR ESTIMATES

- **Body Mounted Accelerometer**

    Selected Weight = 5.0 lbs.

VENDOR ESTIMATES

17.3.3.2 Automatic Control and Stabilization System

Weight Summary

Automatic Control & Stabilization System (ACSS)	33.0 lbs.
Components Circuitry and Installation	26.8 6.2

The ACSS is designed to stabilize and control the LEM in two modes. Mode A is by Reaction Control with main engines off; Mode B is by gimbal control with main engines on. This system is designed to allow deadbands as small as $\pm$ 0.25 degrees and $\pm$ 1 degree per second. An alternate, manual or "fly-by-wire" mode is provided for back-up capability. The pilot may elect to disable the automatic loop of the ACSS and impose manual commands of the Reaction Control System or gimbal actuators.

Gyros (All units are low density type, designed for modular application).

Selected weight, per package = 3.6 lbs.
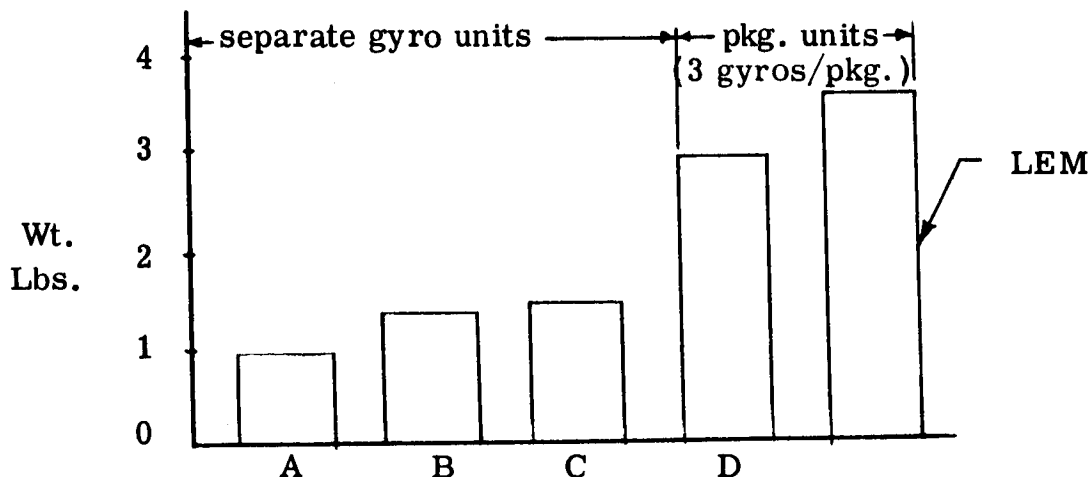
VENDOR ESTIMATES

The remaining items of equipment (amplifiers, pulse generators, autopilot, etc.) are estimates based on functional analyses of component parts of systems for other studies.

17.3.3.3 Reaction Control System

Summary of Weights Substantiated:

RCS	492 Lbs.
Inert	127.2
Propellant & Pressurant	346.7
Circuitry	4.9
Plumbing	13.2

The velocity changes necessary to accomplish separation, rendezvous, docking and stability throughout the descent and ascent phases is provided by the Reaction Control System. Rendezvous is most efficiently performed by the RCS since pilot line of sight control and maneuvering are possible without the necessity of gross maneuvers required when utilizing the main propulsion engines. As a normal extension of the current manned flight operations, nitrogen-tetroxide and Aerozine 50 were selected as propellants. Pressurization of the propellant tanks is provided through redundant regulators by high pressure (3000 psia), stored helium.

The reaction forces are provided by four pitch and four yaw engines, each of 100 pounds thrust, four roll engines of 50 pounds thrust each, and four rendezvous engines of 200 pounds thrust each. Although adequate velocity control for rendezvous is attained by a single 200 pound thrust engine in either the accelerating or decelerating modes, an additional engine is included to provide redundancy. Chambers are pulse width modulated to provide the necessary torques for all operational modes.

Adequate allowances were made to estimate propellant loads conservatively to account for the increased consumption during manual operation and to permit using the RCS for ullage thrust operation. A 12 per cent propellant allowance is also included for reserve.

Component weight estimates obtained from engine manufacturers were used in estimating the weight of the LEM reaction control inert components.

INERT	127.2 lbs.
Propellant Tanks	9.9
Pressurization Tank	7.6
Thrust Chambers, Solenoid Valves, Filters	90.8
Squib Valves	6.9
Check Valves	2.0
Relief Valves	1.0
Bladders	3.0
Filters	2.0
Pressure Regulator	2.0
Burst Diaphragm	2.0

Propellant Tanks

Fuel

Aerozine 50 wt. = 115.3 lbs.

$$\text{Vol.} = 115.3 \text{ lbs.} \times \frac{\text{ft.}^3}{55.4 \text{ lbs.}} = 2.08 \text{ ft.}^3$$

$$\text{Dia.} = (1.91 \times 2.08)^{1/3} = 1.58 \text{ ft.} = 19.0 \text{ in.}$$

$$\text{Area} = 3.14 \times 1.58^2 = 7.85 \text{ ft.}^2 = 1130 \text{ in.}^2$$

$$t_{wall} = \frac{100 \text{ lbs.}}{\text{in.}^2} \times \frac{19 \text{ in.} \times 2 \text{ in.}^2}{4 \times 160,000 \text{ lbs.}} = .0059 \text{ in.}$$

use minimum gage = .015 in.

Shell wt. = 1130 in.^{2} x .015 in. x .160 $\frac{\text{lbs.}}{\text{in.}^3}$ = | 2.7 lbs. |

Supt. Wt. and Fittings.   .25 x 2.7 = | 0.7 |

Welds, Manufacturing Variation, etc. =
.15 x 2.7 = | 0.4 |

Insulation = 1130 in.^{2} x .25 in. x $\frac{4.6 \text{ lbs.}}{\text{ft}^3}$ x

$\frac{\text{ft.}^3}{1728 \text{ in.}^3}$ | 0.7 |

Total Tank Wt. = | 4.5 lbs. |

Oxidizer

N_2O_4 wt. = 230.8 lbs.

Vol. = 230.8 lbs. x $\dfrac{ft.^3}{87.4\ lbs.}$ = 2.65 ft.^{3}

Dia. = $(1.91 \times 2.65)^{1/3}$ = 1.715 ft. = 20.6 in.

Area = 3.14×1.715^2 = 9.22 ft.^{2} = 1330 in.^{2}

t_{wall} = $\dfrac{100\ lbs.\ x\ 20.6\ in.\ x\ 2\ in.^2}{in.^2\ x\ 4\ x\ 160,000\ lbs.}$ = .0064 in.

use minimum gage = .015 in.

Shell Wt. = 1330 in.^{2} x .015 in. x .160 $\dfrac{lbs.}{in.^3}$ = | 3.2 lbs.

Supt. Wt. and Fittings.= .25 x 3.2 = | 0.8

Welds, etc. = .15 x 3.2 = | 0.5

Insul. = 1330 in.^{2} x .25 in. x 4.6 $\dfrac{lbs.}{ft.^3}$ x $\dfrac{ft.^3}{1728\ in.^3}$ | 0.9

Total Tank Wt. = | 5.4 lbs.

Pressurization Tank

Helium Wt. = .6 lbs.

Vol. = .6 lbs. x $\dfrac{ft.^3}{1.75\ lbs.}$ = .34 ft.^{3}

Dia. = $(1.91 \times .34)^{1/3}$ = .866 ft. = 10.4 in.

Area = $3.14 \times .866^2$ = 2.36 ft.^{2} = 340 in.^{2}

t_{wall} = $\dfrac{3000\ lbs.\ x\ 10.4\ in.\ x\ 2\ in.^2}{in.^2\ x\ 4\ x\ 160,000\ lbs.}$ = .0975 in.

Shell Wt. = 340 in.^{2} x .0975 in. x $\dfrac{.160\ lbs.}{in.^3}$ = | 5.3 lbs.

Supt. Wt. and Fittings= .25 x 5.3 | 1.3

Weld, etc. = .15 x 5.3 = | 0.8

$$\text{Insulation} = 340 \text{ in.}^2 \times .25 \text{ in.} \times$$

$$4.6 \frac{\text{lbs.}}{\text{ft.}^3} \times \frac{\text{ft.}^3}{1728 \text{ in.}^3} = \qquad 0.2$$

Total Tank Wt. = 7.6 lbs.

Thrust Chambers, Solenoid Valves, Filters | 90.8 lbs.

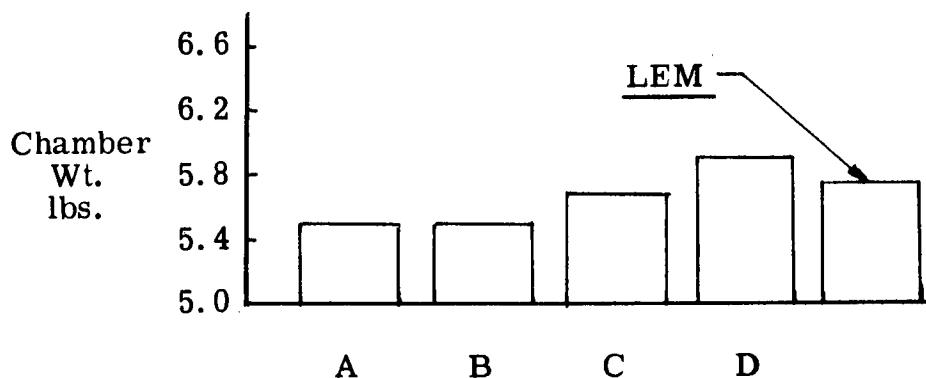- 50 lb. thrust unit @3.70 lbs. x 4 req'd. = 14.8 lbs.

  This estimate is based on one vendor's input on experimental hardware

- 100 lb. thrust unit @ 5.75 lbs. x 4 req'd. = 46.0

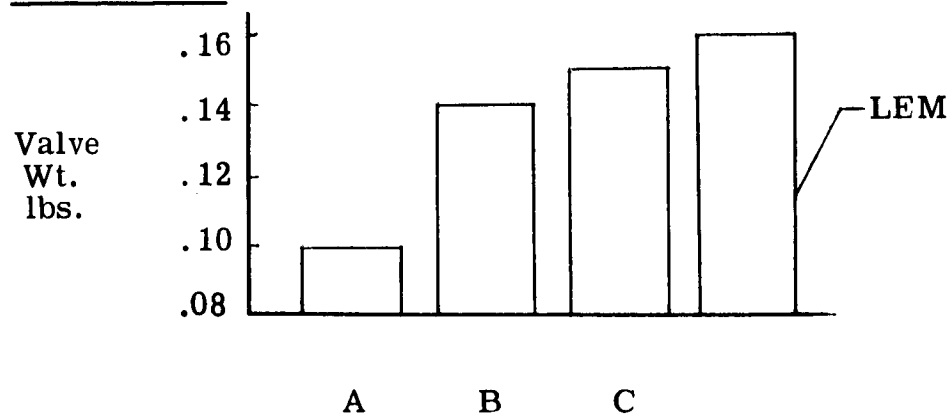
VENDOR ESTIMATES

- 200 lb. thrust unit, est. @ 7.5 lbs. x 4 req'd = 30.0

Squib Valves @ .16 lbs. x 43 req'd. = | 6.9 lbs.

VENDOR ESTIMATES
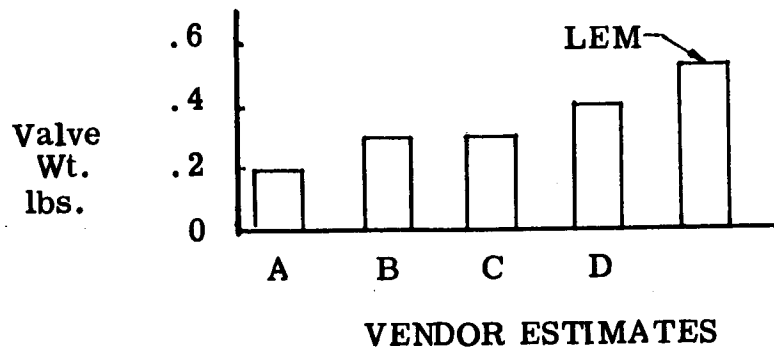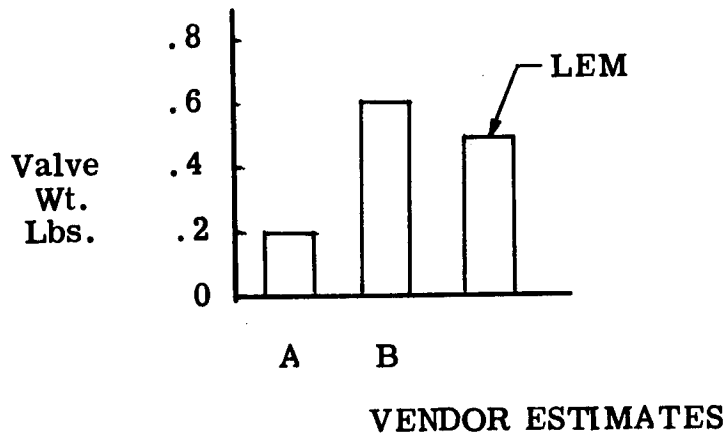
Check Valves @ 0.5 lbs. x 4 req'd. = | 2.0 lbs. |

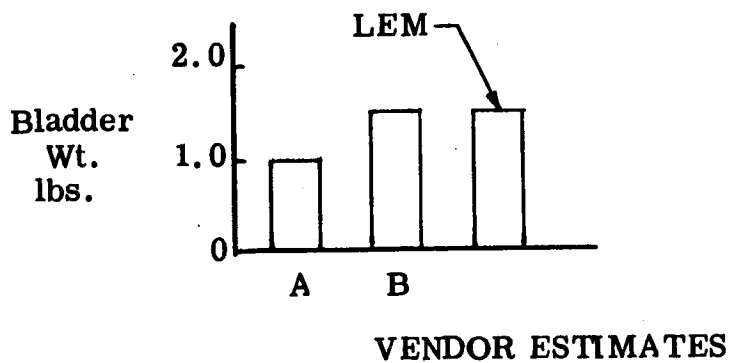Relief Valves @ 0.5 lbs. x 2 req'd. = | 1.0 lbs. |

Bladders @ 1.5 lbs. x 2 req'd. = | 3.0 lbs. |
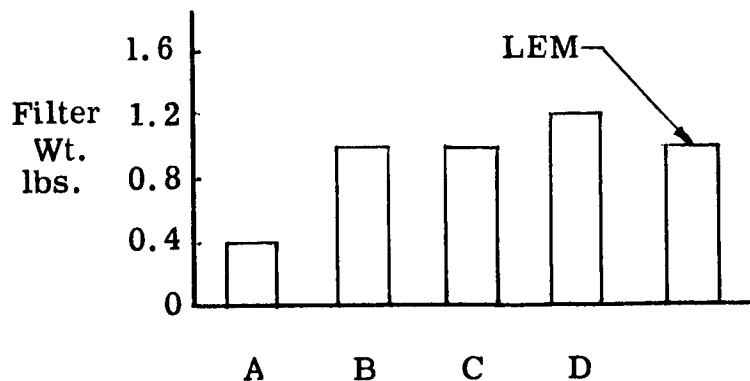
Filters @ 1.0 lbs. x 2 req'd. = | 2.0 lbs. |

VENDOR ESTIMATES

Pressure Regulators @ 1.0 lbs. x 2 req'd. = | 2.0 lbs. |
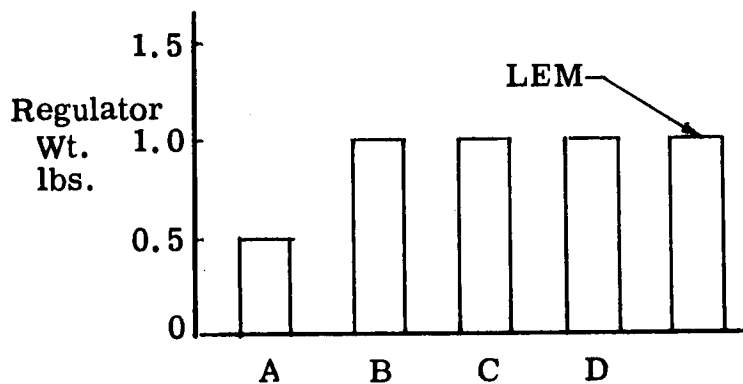
VENDOR ESTIMATES

Burst Diaphram est. @ 0.5 lbs. x 4 req'd. = | 2.0 lbs. |

PROPELLANT AND PRESSURANT	346.7 lbs.
Propellant	(346.1)
Consumed	
Fuel	103.0
Oxidizer	206.0
Reserve	
Fuel 12% of consumed	12.3
Oxidizer 12% of consumed	24.8
Pressurant	(0.6)
Consumed	0.5
Reserve 25% of consumed	0.1

Calculations for the propellant and pressurant are shown in Section 7.0, the Reaction Control System.

CIRCUITRY	4.9 lbs.
Assumed AN-20 shield wire for average unit weight	
$.0023 \frac{lbs.}{in.}$ x 1564 in. =	3.6
Electrical hardware = 36% of wire weight =	1.3

PLUMBING	13.2 lbs.
1/2 in. x .035 steel	
$.0145 \frac{lbs.}{in.}$ x 40 ft. x $\frac{12 \text{ in.}}{ft.}$ =	7.0
1/4 in. x .049 steel	
$.0088 \frac{lbs.}{in.}$ x 40 ft. x $\frac{12 \text{ in.}}{ft.}$ =	4.2
Hardware=18% of tubing weight	2.0

17.3.3.4 Environmental Control Section (ECS)

Summary of weights justified:

ECS	503.8 lbs.
Suit Circuit	70.9
Cabin Circuit	33.5
Thermal Loop	132.2
Water Loop	79.5
Oxygen Supply Loop	101.0
Electrical and Mechanical Hardware, including the Airlock Air Distribution System	86.7

A 5 psia pure oxygen atmosphere system with a temperature range between 68 and 76°F and a 30 to 60 per cent humidity range is recommended for the HS-625 vehicle. The methods used to accomplish the various requirements are outlined.

(a) Oxygen Storage - supercritical cryogenic storage for normal supply; high pressure, gaseous for the emergency supply.

(b) Carbon Dioxide Removal - by Lithium Hydroxide.

(c) Humidity Control - by condensation in the temperature control heat exchanger and separation of the water from the airstream by a centrifugal separator.

(d) Contaminate Control - by activated charcoal and a hopcalite catalytic burner.

(e) Internal Thermal Control - a water/etholyne glycol heat transportation loop and space radiator.

(f) External Thermal Control - passive system that achieves thermal balance through utilization of insulation and thermal coatings.

An analytical approach is used to justify the weight of the environmental control system. The very high degree of detail shown in the system weight breakdown (Section 17.2.1) also substantiates the estimates made.

(a) Water and Water Tankage (83.7 lbs.). The water and water tankage include the following:

	Fluid Weight	Tankage Weight
(1) Waste water tank - capacity 16.5 lbs.	----	5.1
(2) Cooling water	53.3	8.8

The 53.3 lbs. of drinking and cooling water is fixed by the heat loads which must be dissipated by water cooling during transient peak load conditions and by metabolic and wash water requirements. The fuel cell water generated fills part of these requirements. These transient heat loads occur during checkout, landing, launch and rendezvous with periodic short increases in vehicle power usage during the period on the lunar surface. The cooling water required has been calculated based on the integrated

values of these peak heat loads for the complete mission. The equation used to calculate the weight of cooling water, W_w, is as follows:

$$W_w = \frac{Q_t}{h_{f_g}}$$

where: Q_t = integrated transient heat loads over the complete mission (i.e., heat loads above the capacity of the vehicle radiator) - BTU's

h_{f_g} = heat of vaporization of the fluid at the design boiling temperature - $\frac{BTU}{lbs.}$

The drinking and wash water requirements (9.5 lbs.) are fixed by the amount of water required per man per day (4.75 lbs.). This value is commonly accepted for space vehicle design.

Waste water tankage capacity is a function of the amount of urine, sweat, water exhaled and wash water. Again, man's average requirements are well documented and commonly accepted.

Figure 17-4 shows justification for the water tank weights used. Tank weight is plotted as a function of fluid weight from estimated vendor data on other systems. The actual hardware weight for the Mercury water tank is shown on the curve and is significantly higher than the estimated values. The HS-625 weights were chosen as a reasonable average between installed Mercury weights and the estimates.

(b) <u>Oxygen and Oxygen Tankage</u> (92.9 lbs.)

The oxygen and oxygen tankage weight include the following:

(1) Normal O_2 supply (50.0) lbs.
    Metabolic requirements 2 lbs/man-day   4.19
    Leakage at 0.1 lbs/hour   2.51
    2 cabin repressurizations 11.2 lbs. each   22.40
    4 airlock operations at 1.05 lbs. each   4.20
    50% excess   16.70

Note: Refills for backpacks to be taken from the 50% excess and from the normal metabolic supply.

(2) Normal O_2 tankage   30.0 lbs.

(3) Rendezvous Oxygen - Gaseous   4.0 lbs.
    Rendezvous Oxygen Tank   8.9 lbs.

The 2 lbs/man-day metabolic O_2 requirement is the accepted average daily metabolic requirement. The assumed leakage rate of 0.1 lb/hr. was established during the Apollo proposal effort and is based on extrapolated Project Mercury data. Two cabin repressurizations are provided for the Apollo vehicle and are included for the LEM. One cabin repressurization is

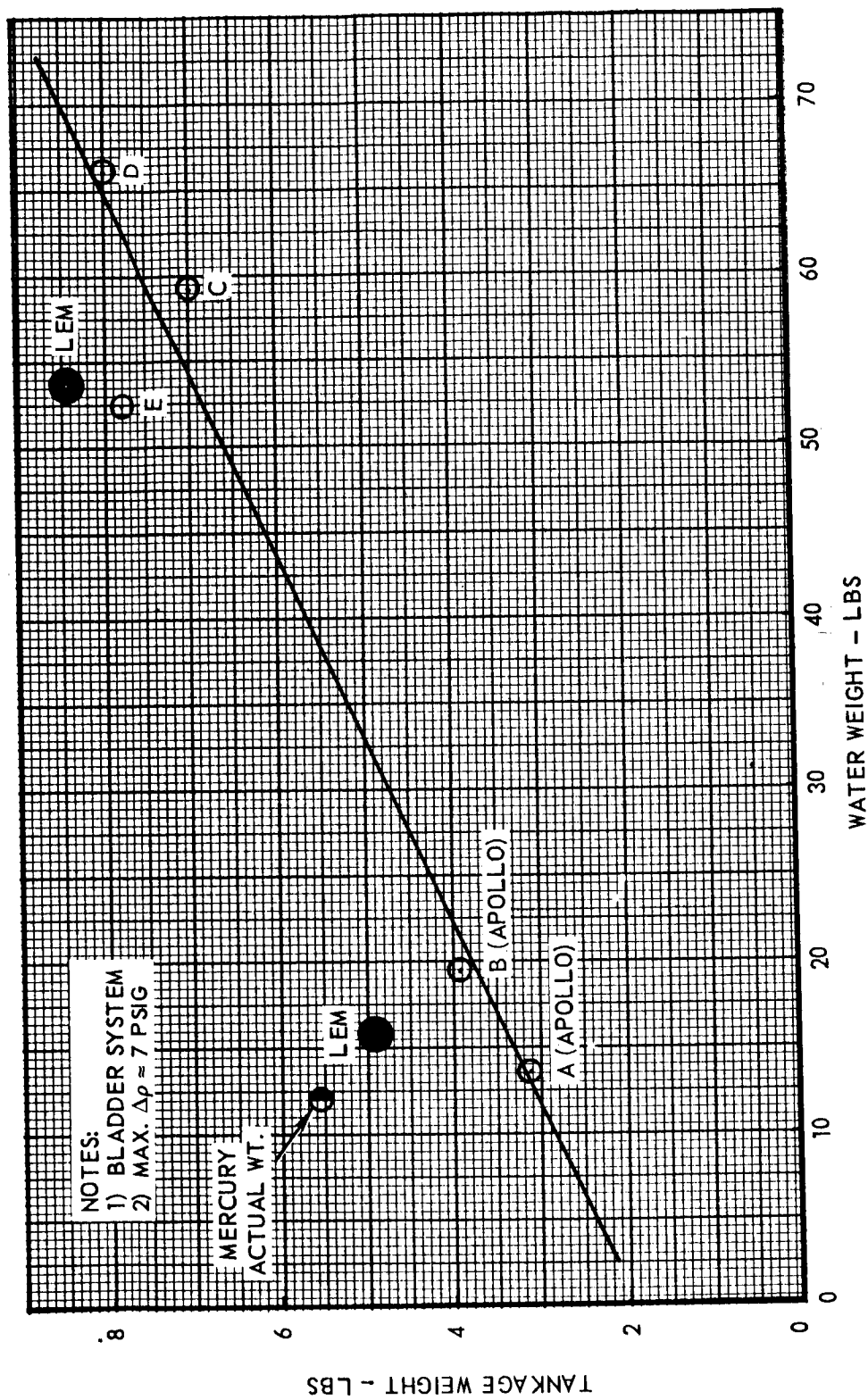Figure 17-4   WEIGHT OF SPACE VEHICLE WATER TANKAGE

NOTES:
1) BLADDER SYSTEM
2) MAX. $\Delta\rho \approx 7$ PSIG

MERCURY
ACTUAL WT.

LEM

A (APOLLO)
B (APOLLO)

TANKAGE WEIGHT – LBS

WATER WEIGHT – LBS

required for the initial filling and one is required as a contingency. The 4 airlock operations are based on the expected entrance and exit requirements. This provides for two trips outside the HS-625 vehicle. The 50% excess oxygen is the same as the current Apollo specification requirements and includes provisions for excessive leakage, backpack refills, boil off, etc.

Figure 17-5 shows the justification for the LEM ECS cryogenic O_2 tankage assembly weights. The data presented in ASD-TR 61-162 dated December 1961 has been used as the basis for the LEM weights. These data are based on AiResearch experience on this type cryogenic tankage. The AiResearch and Hamilton Standard estimates for Apollo were considerably lighter than the TR 61-162 data because titanium tankage was proposed. Subsequently a problem of materials compatibility has arisen and titanium tanks are not recommended for cryogenic oxygen storage.

(c) CO2 and Odor Removal System (LiOH + activated charcoal) (16.9 lbs.)

For a 1-day mission, this system consists of 2 canisters containing sufficient LiOH and activated charcoal for removal of the CO_2 and odors generated. Figure 17-6 shows a comparison of the HS-625 weights with available active and calculated weights. Also shown on Fig. 17-6 is a curve representing the weight of LiOH required for 100% absorptive efficiency. The weight between these two curves represents the weight of the charcoal, hardware, filters, etc.

For mission durations exceeding 1 day, it is planned that two hard canister housings be available with one day duration, lightly packaged, chemical canisters for each day of mission time. This arrangement will reduce the weight over that shown by Figure 17-6 since the major hardware penalty is associated with the hard, pressure tight canister.

(d) ECS Radiator (31.5 lbs.)

The ECS radiator for "cold" side landings has been sized based on the integrated average load while at rest on the lunar surface. As noted above, cooling water is used for transient peak load conditions. Based on the current electrical heat loads and a maximum equipment cold plate temperature of $160^{\circ}F$, the radiator area required is 35 ft^2. Past calculations have shown that structurally integrated glycol radiators operating in this temperature range weigh approximately 0.9 lbs/ft^2 and this is the basis for the current weight estimate. This estimate depends first on determining the optimum fin thickness, tube spacing, tube size, and micrometeorite protection requirements. Once these calculations are made, the weight is determined in a similar manner to the methods used to define the vehicle structural weight.

ASD-TR 61-162, December 1961. "Analytical Methods for Space Vehicle Atmospheric Control Processes - Part 1".
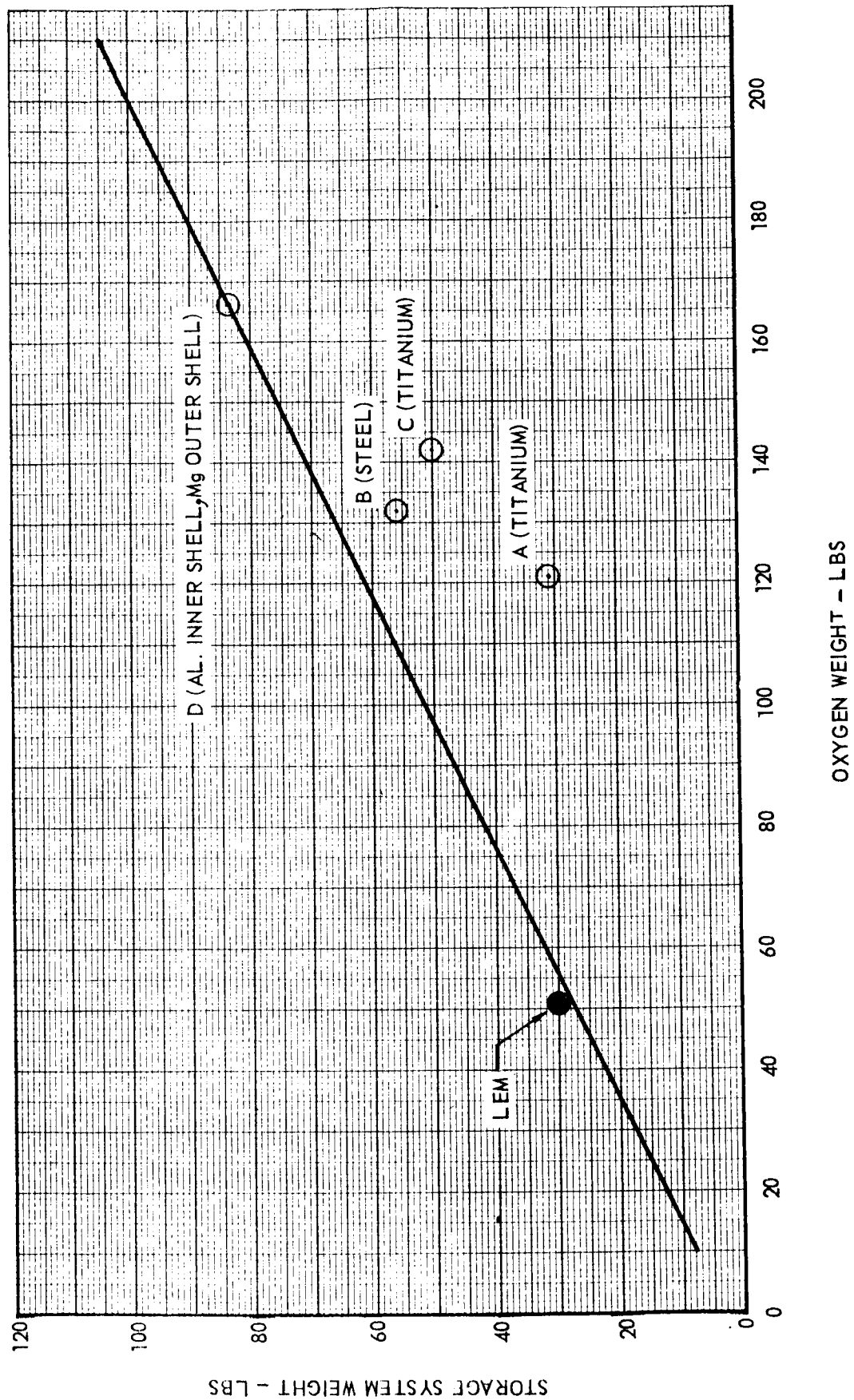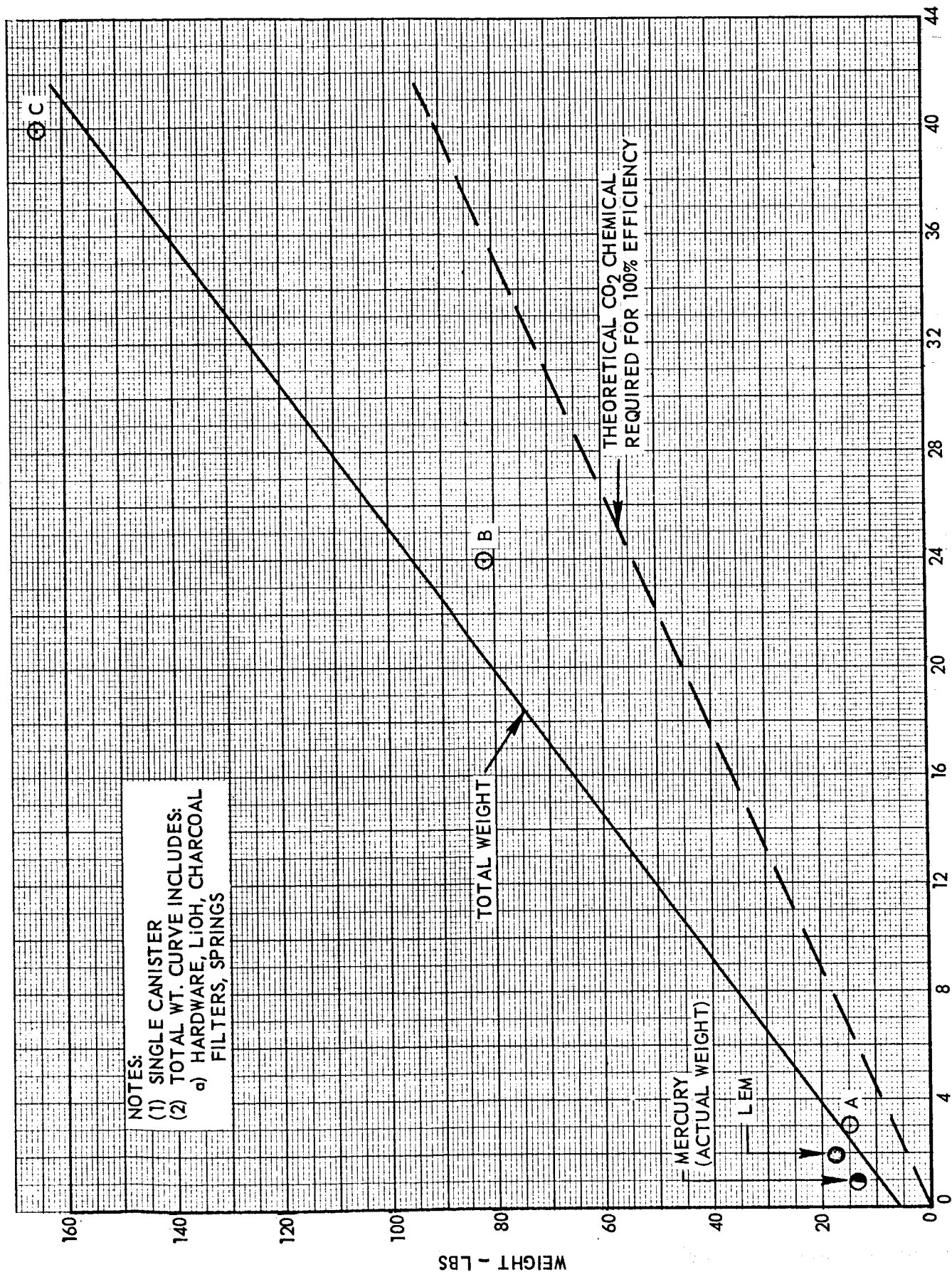
Figure 17-5 WEIGHT OF SUPERCRITICAL OXYGEN STORAGE SYSTEMS

MISSION DURATION – MAN-DAYS

Figure 17-6 **LiOH PLUS CHARCOAL REQUIRED**
WEIGHT VS MISSION DURATION

(e) <u>Equipment Cold Plates</u> (64.6 lbs.)

Estimation of an accurate weight for the equipment cold plates is somewhat difficult since the proposed design is unique. It is recommended that the cold plates contain water and water wicking for emergency cooling and glycol flow passages for normal cooling. (See sketch below)
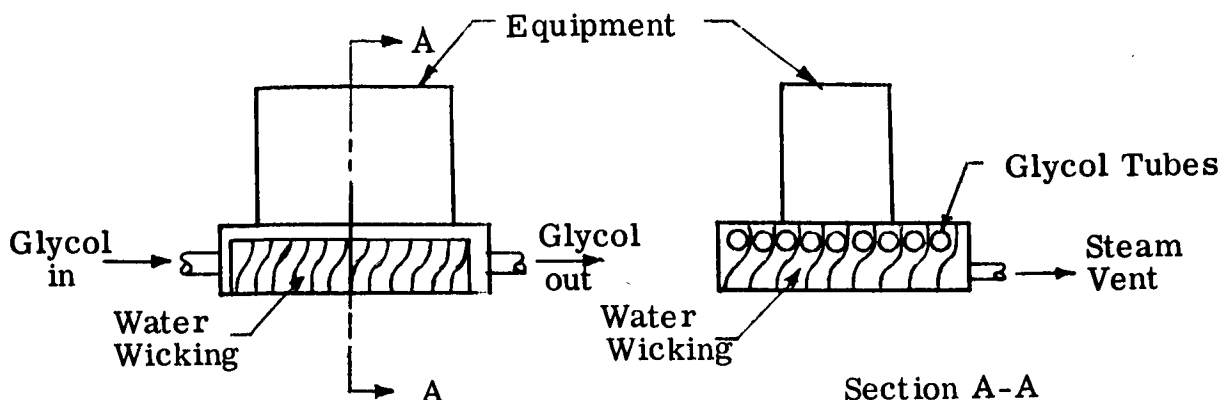
As shown by the above sketch the construction of the cold plates would be closely akin to the construction of a shell and tube heat exchanger. Shell and tube heat exchanger core weights which have been obtained in compact aircraft type heat exchangers are approximately 34.1 lbs/ft^3 for aluminum construction and 62.4 lbs/ft^3 for steel construction. (Reference ASD TR 61-162 dated December 1961)

Accurate surface area requirements for cold plates are not available. Based on Apollo design experience, approximately 10 ft^2 of cold plating will be required.

The emergency cooling water weight is determined by the heat loads and the time required for abort. The water weight is 34.3 lbs. based on current heat loads and a 4 hour time requirement. Using quoted values for heat exchanger core weight based on aluminum construction, the core weight for 10 ft^2 of cold plates, 3/4 inches thick, is 21.4 lbs. (Core volume = 0.626 ft^3)

This weight is for the basic core only. The weights of manifolds, header plates and supporting structure are not included. Studies of weights of production heat exchangers for aircraft application indicates that the total weight may be related to the core weight by the following equation:

$$\frac{W_{total}}{W_{core}} = (\frac{12}{V})^{.118}$$

where: V = core volume in ft^3

Using this equation, the estimated total hardware weight for the cold plates is 30.3 lbs.

(f) Miscellaneous Ducting, Plumbing, and Other Installation Hardware (86.7 lbs.)

Mercury experience has been used as the basis for the estimate of the LEM installation hardware weights. The breakdown on the Mercury environmental control system is as follows:

		% Total Wt.
(1)	Major Hardware - valves, heat exchangers, storage tanks, compressors, etc. (dry)	50.0%
(2)	Expendable materials, i.e., H_2O, O_2, LiOH	21.8%
(3)	Misc. hardware for installation, i.e., brackets, ducts, lines, seals, clamps	19.4%
(4)	Misc. electrical installation hardware (controls, cables, sensors, indicators, switches, etc.)	8.8%
		100.0%

Based on the above values for installation hardware, a value of 20% was selected for the LEM weight estimate. This allows 15% for mechanical hardware and 5% for electrical hardware.

The above items account for approximately 80% of the total ECS weight. The remaining 20% includes valves, compressors, separators, pumps, etc. For these items, weights have been obtained from vendor estimates on Apollo and from actual hardware weights on Project Mercury.

17.3.3.5   Electrical Power System

Summary of weights justified:

Electrical Power System	888.0 Lbs.
Fuel Cell System	538.0
Battery System	200.0
Distribution System and Circuitry	150.9

The fuel cell system, which supplies power during the descent and lunar stay phases of the mission, is composed of three identical modules, each operating into parallel buses. Output voltage is a nominal 28 volts d.c. The reactants, hydrogen and oxygen, are stored cryogenically in a redundant tank system. After the fuel cells have been off-loaded on the moon, silver-zinc batteries supply power for the ascent and rendezvous phases. Power distribution is accomplished manually using circuit breakers designed to protect the circuitry. Manual override of all automatic functions is provided. The level of power supplied is approximately 1.5 kw during the lunar stay and 2.5 kw during the descent and rendezvous phases.

FUEL CELL SYSTEM		538 lb
Propellant and Tankage		76.7
Fuel Cells		
Cell module, electrolyte, case	(3)	270.0
Controls	(3)	150.0
Pressure Regulator	(8)	6.0
Heat Exchanger		6.0
Valves		29.0

Propellant and Tankage		76.7 lbs.
Propellant		(51.3)
Oxidizer - oxygen		45.6
Fuel - hydrogen		5.7
Tanks		(25.4)
Oxidizer	(2)	14.0
Fuel	(2)	11.4

Oxidizer Tank - spherical (2219-T81 aluminum)

$$\text{Volume} = \frac{45.6 \text{ lbs.}}{71.6 \text{ lbs/ft}^3} \times .5 = .319 \text{ ft}^3 = 550 \text{ in}^3$$

Expansion allowance = 5% volume increase

$$\text{Diameter} = (1.91 \times 578)^{1/3} = 10.4 \text{ in.}$$

$$\text{Area} = 3.14 \times 10.4^2 = 340 \text{ in}^2$$

$$t_{wall} = \frac{800 \text{ lbs/in}^2 \times 10.4 \text{ in.} \times 2}{4 \times 27,000 \text{ lbs/in.}} = .154 \text{ in.}$$

Shell wt. $= 340 \text{ in}^2 \times .154 \text{ in.} \times .100 \frac{\text{lbs}}{\text{in}^3} =$	5.2
Supports= 20% of shell weight =	1.0
Manufacturing variation, welds = 10% of shell weight	.5
Insulation $\left(.25 \text{ in.} \times 340 \text{ in}^2 \times \frac{4.6 \text{ lbs/ft}^3}{1728 \text{ lbs/in}^3}\right) 2 =$	.4
Total weight per tank (2 required)	7.1 lbs.

Hydrogen Tank - spherical (Mag outer shell; Ti inner shell)

from the plot below, $\dfrac{W_T}{W_u} \approx 2$

since $W_u \doteq 2.85$

Tank weight $\doteq 5.7$ lbs. for each of 2 req'd.

TOTAL VESSEL WEIGHT PENALTY
SUPERCRITICAL HYDROGEN STORAGE

Weight penalty

$\dfrac{W_T}{W_u}$
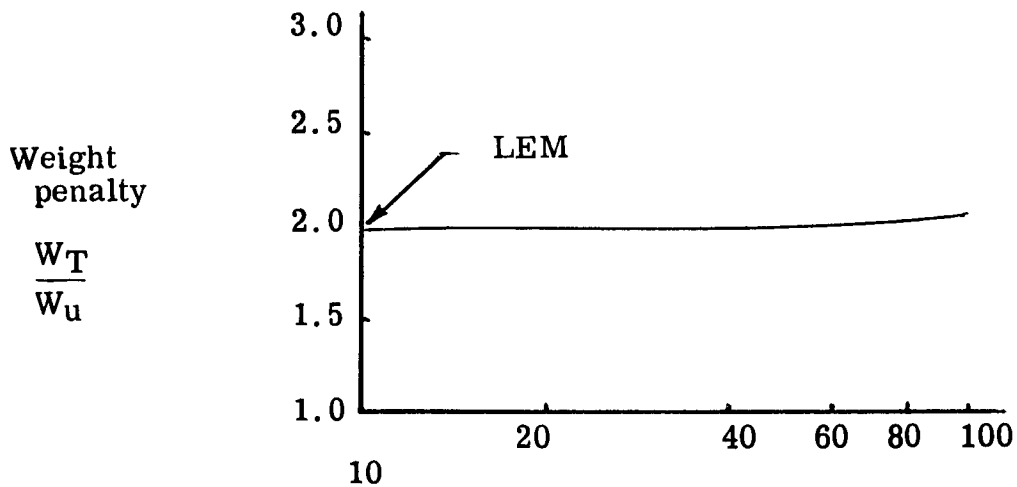
Useful Fuel Load - Lbs.

(Ref: ASD TR-61-162, Figure 63, p. 154)

Fuel Cell			420 lbs.
Electrolyte and Case	90 x 3 required =		270
Controls	50 x 3 required =		150

Fuel Cell
Weight -
Lbs.

Peak Kilowatt Rating (@ 24V-dc)
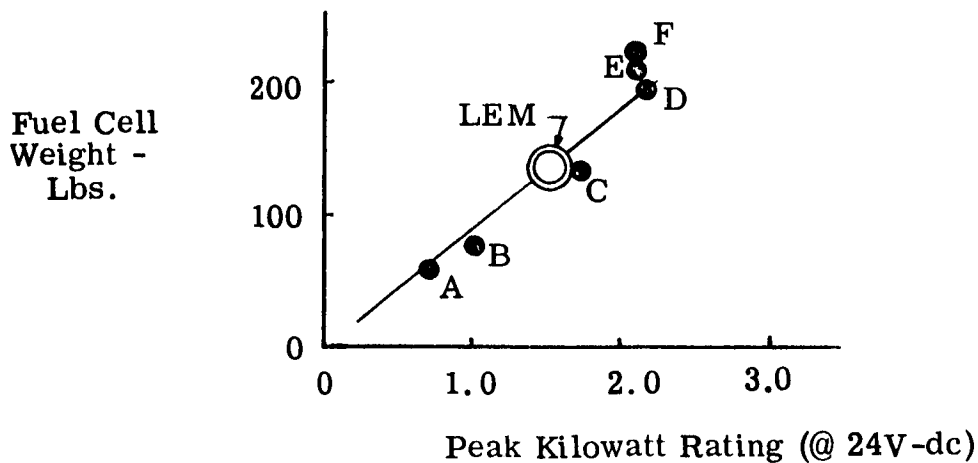
Pressure Regulator

Selected weight for 8 required = 6.0 lbs.
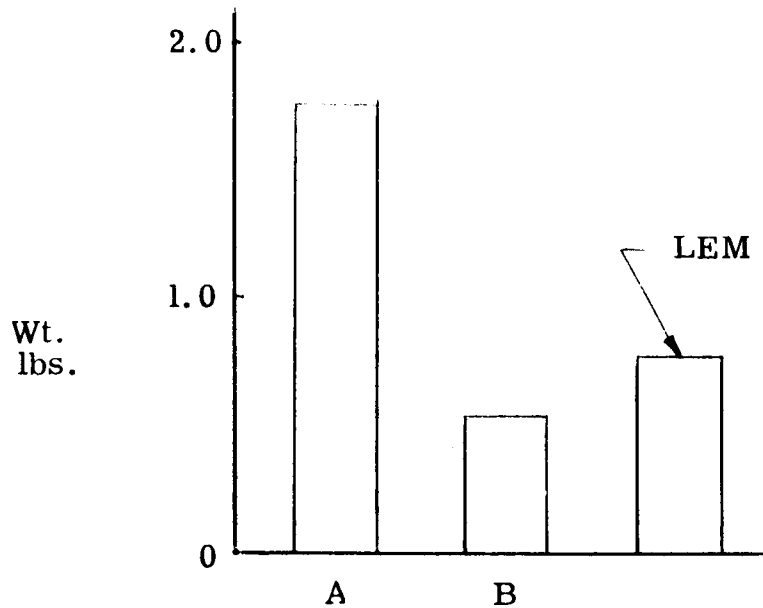
VENDOR ESTIMATES

The "A" data is a 4-series/parallel arrangement; the "B" data is a single unit. Single units are recommended for reliability.

Heat Exchanger (Glycol/Hydrogen)

Selected weight for 3 required = 6.0 lbs.

Capacity (BTU/hr.)
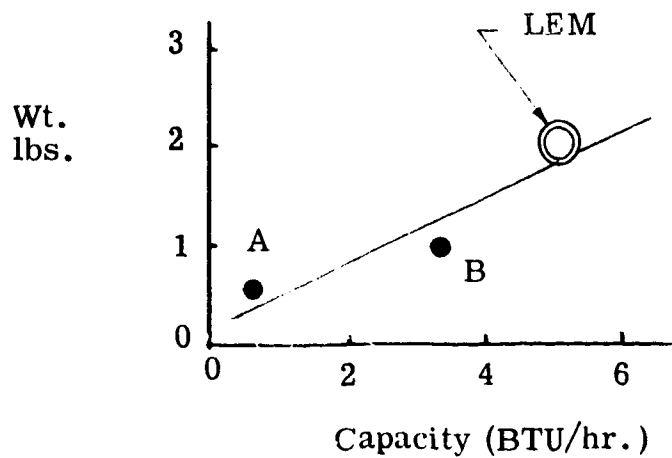
Valves	29.0 Lbs.
Selected weight for 14 shut-off valves =	21.0
Selected weight for 4 fill and vent valves =	8.0
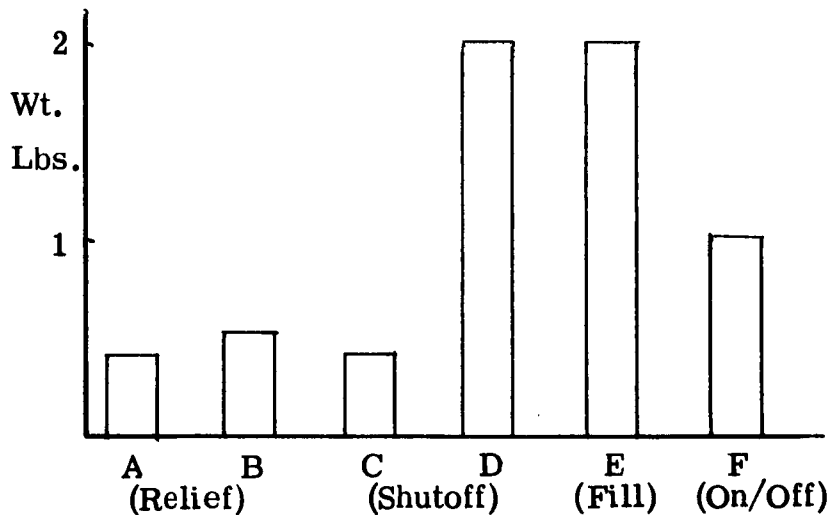
VENDOR ESTIMATES (B, F) AND STUDY DATA

BATTERY SYSTEM   (2)   200 lbs.

Single Battery

LEM
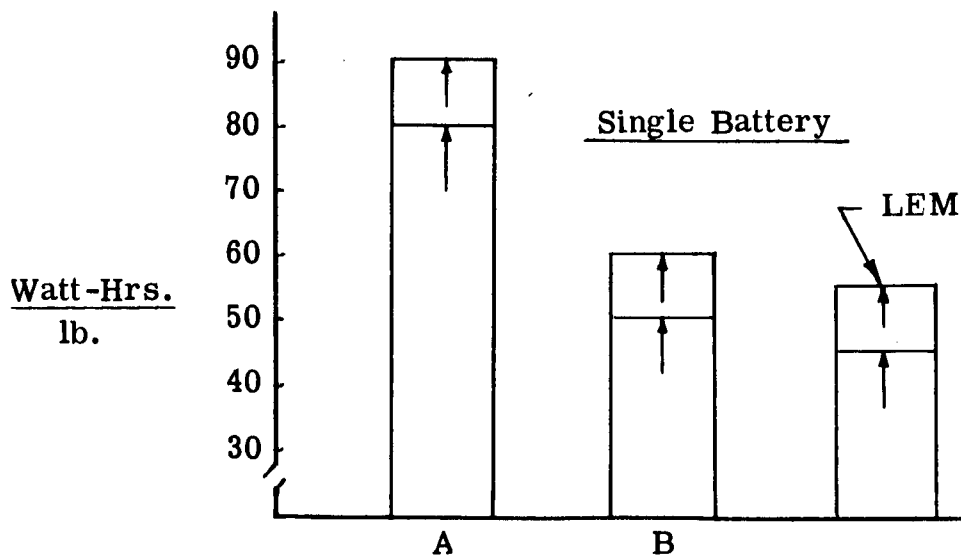
50 watt-hours/pound selected for design

5000 watt-hours ÷ 50 watt-hours/lb. = 100 lbs. per battery

DISTRIBUTION SYSTEM 150.0 Lbs.

STUDY DATA (Mercury, Scout, Apollo SM, Apollo CM)

17.3.3.6   Communications

Summary of weights by mode:

Communication System		128.4 lbs.
Man-to LEM	VHF	4.6
LEM-to-Lunar Orbiting Vehicle	243 mc	23.8
Moon-to-Earth	2295 mc	58.8
Earth-to-LEM	2215 mc	9.2
Circuitry and Installation		32.0

Communications between the points listed above is provided by this system. The feasibility of providing the desired capabilities on each channel has been evaluated in terms of r-f output power, since this is the main factor in determining size and weight. Most of the preliminary study time was spent in determining the actual tasks to be performed by the communications gear. Therefore, it was not possible to request and receive a sufficient amount of vendor data on individual items to allow a statistical compar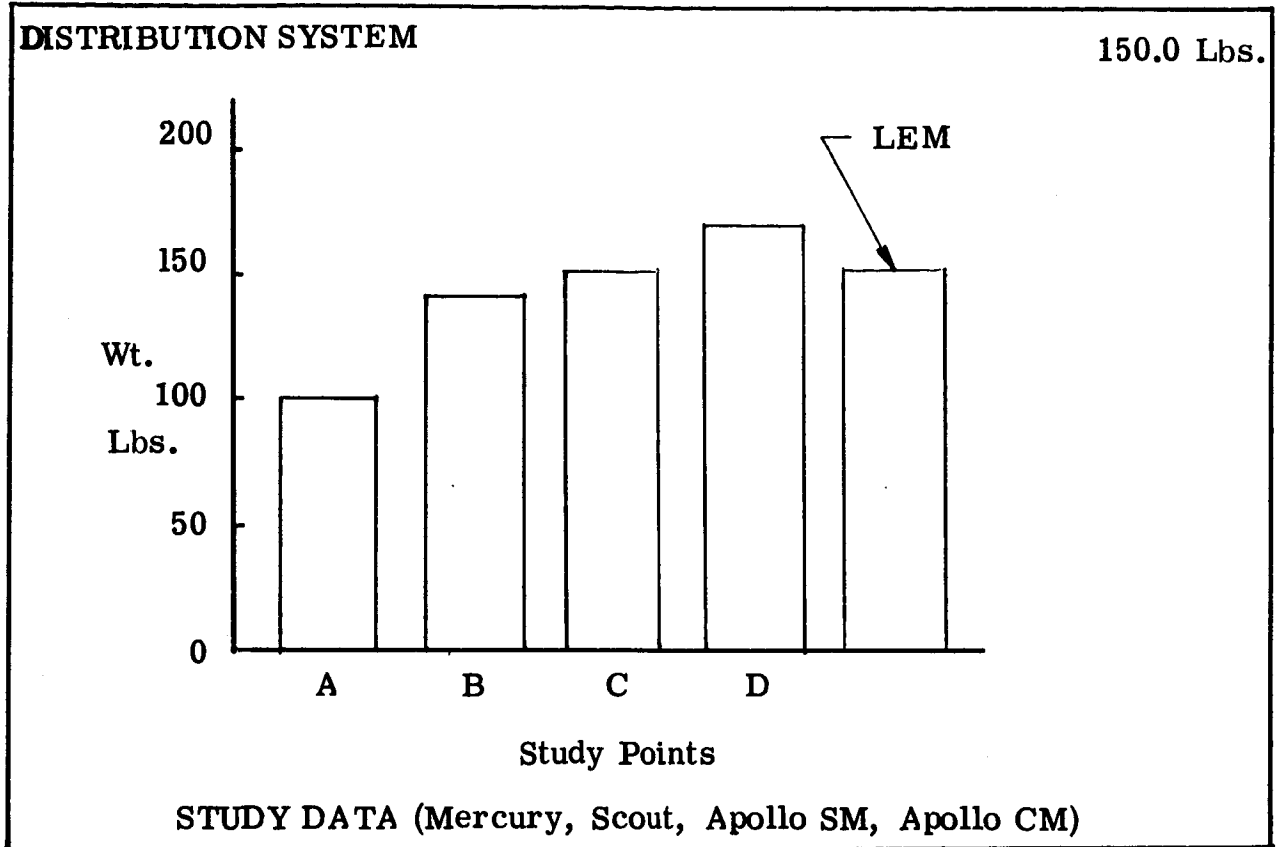ison. The sources used for the weights presented are shown in the table below. It should be noted that, although the selected weights were multiplied by two to insure reliability through redundancy, the final weights (in the Detail Weight Breakdown, Section 17.2) cannot be derived simply by doubling the tabulated weights. This is so because in analyzing the circuitry in the equipment represented by the tabulated data, some of the electronic hardware was found to be not applicable for the HS-625 requirement.

Research on transmitter data reveals a relationship between weight and output power of one (1) for state-of-the-art equipment. The estimated weight of the transmitter selected is based on a 2 pounds per watt of output power which provides for reliability.

VHF GEAR	ACTUAL WEIGHT	
	Lbs.	Ounces
Man-to-LEM and 243 mc LEM-to-LOV		
A. Beacon acquisition telemetry transmitter		
Motorola - off-the-shelf unit	1	3
B. Receiver		
LEL Inc. - missile application unit		11.5
C. Power Amplifier		
Hughes	6	
UHF GEAR		
2295 mc		
A. S-Band Transponder		
MARK I unit for RANGER spacecraft	12	4
B. Power Amplifier		
Resdel Engr. Corp. - cavity type, for		
RANGER spacecraft	4	4
2215 mc		
A. Receiver		
Motorola unit	4	10

17. 3. 3.7   Instrumentation

Summary of weights justified:

Instrumentation System	78. 0 lbs.
T.V. and Camera Systems	21. 4
Data Acquisition System	22. 5
Transducers, Calibrator and Power Supply	14. 0
Circuitry and Installation	20. 1

The instrumentation system is comprised of transducers, data handling equipment, television cameras, and pilots display meters. On the basis of system accuracy attainable within the communications link power and bandwidth restraints, a PCM (Pulse Code Modulation) data handling system was selected.

Vendor weight data were used as the basis of estimating system weights except in the case of transducers and signal conditioners which are based on past experience.

T.V. and Camera Systems (without Cine Cameras)	21.4 lbs.
Real Time T.V. Camera	(10. 0)
Hallomore Elect. Div., Mod. 0594 Camera	6. 0 act.
Lens, etc., estimated	4. 0
Cine (Motion Picture) Camera and Film (2)	20. 0 act.

(Note: transferred from the Command Module)
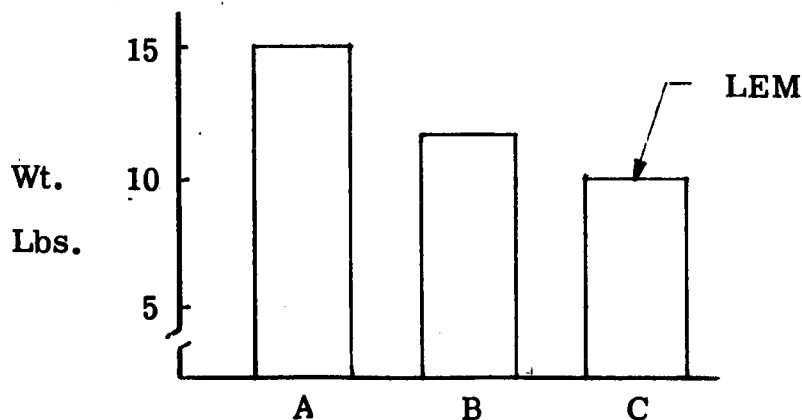
Vendor "C"s Camera was evaluated as technically superior and with greater film capacity, though lighter weight, than A and B.

Film Developing Unit	Rapromatic, Inc. - web process	(5.0) act.
Film Storage Container (8)		(6.4)

PCM Data Acquisition System - Hughes Aircraft Company

     A. In general, data acquisition systems are not listed as "off-the-shelf" items. The accepted procedures for quotations on such equipments are as follows:

     (a) Detailed specifications are formulated by the customer.
     (b) A manufacturer will develop a complete system per requirements of the specification.

     B. Considerable technical information is available to indicate that current state-of-the-art components and proven circuit design techniques can be combined to realize the physical characteristics listed for Hughes Aircraft.

Additional sources of manufacture are:

     (a) Electro-Mechanical Research, Inc.
     (b) United Electrodynamics
     (c) Radiation, Inc.

17.3.3.8   Scientific Payload

     The breakdown and total weight of Scientific Payload used in the HS-625 vehicle was suggested by NASA. However, in an independent survey conducted during the study, a breakdown similar in purpose and in weight was developed. This subject is treated in depth in Section 15.0, Volume II.

Selected weight = 215.0 lbs. (per NASA)
(see Section 17.2.1 for a detailed weight breakdown)

17.3.3.9   Displays and Controls

Summary of weights justified:

Display and Control System	141.0 lbs.

     This system provides the arrangement for presenting the controls and displays necessary for the crew to exercise control over the vehicle and its subsystems.

     Individual display and control components were assigned to each subsystem based on an operational analysis. The very high degree of detail shown in the system breakdown (Section 17.2.1) partly substantiates the weight of the display and control system. Mercury, Apollo and BMD (SR-17532 Permanent Satellite Base and Logistics Study) display and control system weights were plotted against the total weight of subsystems represented. The LEM system compares well with the trend data. It should be noted that the weight estimate of the system is closer to Mercury than to Apollo. An explanation of this follows.

	Apollo lbs.	LEM lbs.
1. Communications		
Closed circuit TV and displays	72.0	0
2. Navigation and Guidance, ACSS		
Attitude Director	26.0	15.0
RCS Panel	7.5	2.7
Trajectory Error Indicator	8.0	0
Yaw Controllers (2)	10.0	0
Side Controllers (3)	12.1	----
Attitude Controller (2)	----	8.0
3. Propulsion		
Vernier Panel	7.0	0
Terminal Panel	7.0	0
Retro Panel	7.0	0
Thrust Controller	0	3.5
4. ECS Panel	20.0	6.9
5. Structure - Board and Consoles	60.0	22.0
6. Miscellaneous Panels, Instruments, and Circuitry	63.4	82.9
SYSTEM TOTAL	300.0	141.0

Reasons for Differences

Navigation and Guidance, ACSS
    a. Yaw control function built into side controller
    b. LEM attitude control much less complex
    c. LEM data readouts are simplified because of single type data for the landing/launch part of LOR mission only

ECS Panel
    a. The Service Module functions are controlled and monitored from the ECS panel in the Command Module; LEM requirements considerably reduced

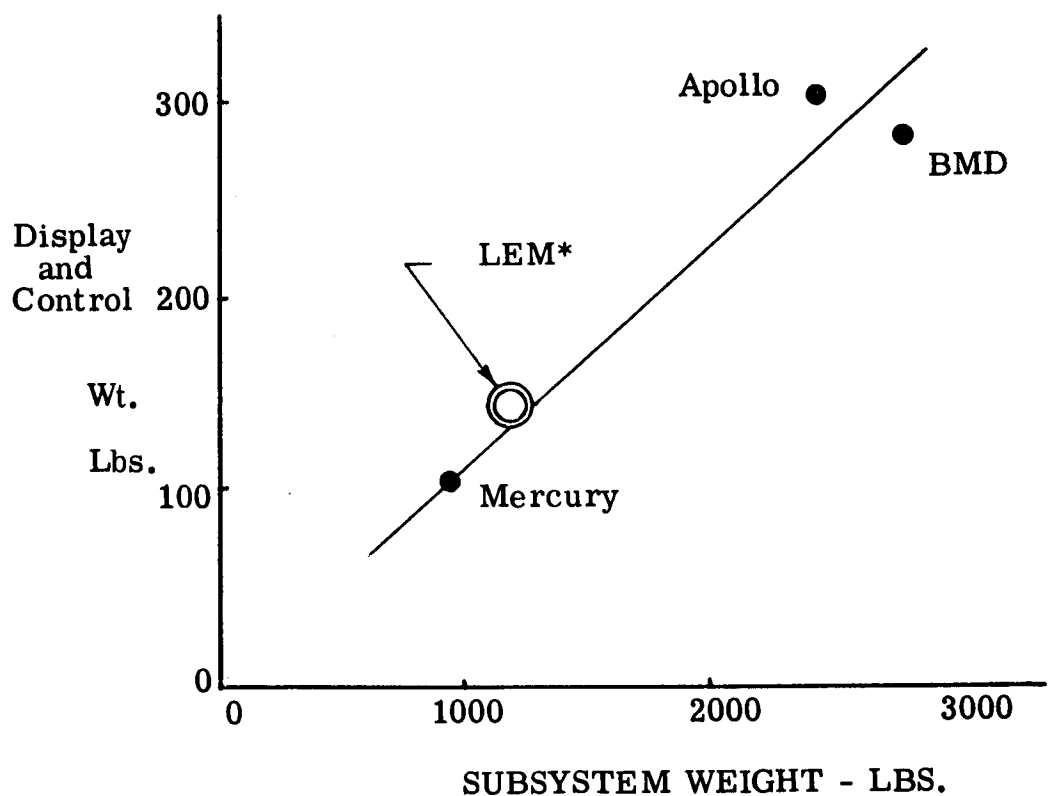Support Structure
    a. Reduction is due to physical size of display board and consoles Apollo approximately 25.4 ft^2 compared to 7.6 ft^2 in LEM

DISPLAY AND CONTROL SYSTEM
WEIGHT
VS
SUBSYSTEM WEIGHT

*Includes current hardware catalogue weights.

17.3.3.10   Crew Support

Summary of weights justified:

Crew and Crew Support		661.5 lbs.	
Crew - 95 percentile	(2)	380.0	0
Pressure suits	(2)	60.0	0
Food			3.6
Self-Maneuvering unit	(1)	115.0	0
Furnishings			2.9
ECS backpacks	(2)	60.0	0
Seat and restraint	(2)		40.0
Transferred from Command Module of Apollo		615.0	
Permanently located in Crew Station of LEM			46.5

The crew support system is designed to provide the basic suiting, restraining and nourishment requirements for the two-man crew selected. In addition, emergency environmental protection and free space maneuvering capability are provided.

The weight estimates are based on a detail analysis of the requirements using conservative estimates for hardware.

Suit System   Wt.-Lbs.
                                                                      60.0

1. NASA RFP No. MSC-62-26P
     "Apollo Spacesuit Assembly"

2. Item (1) quotes a weight for suit and ECS
     backpacks (2)   120 lbs.

3. Estimated breakdown of units: Suit (2)   60 lbs.
                                    Backpack (2) 60 lbs.

Food and Water   3.6

1. Dehydrated food and packaging   3.6
2. Water included in ECS (27.3 lbs. total for crew)

	Wt-Lbs.
Self-Maneuvering Unit	**115.0**

(Weight estimate made under Contract A F 33(616)-8197
"Feasibility of a Self-Maneuvering Unit for Orbital
Maintenance Workers")

Propulsion	
H_2O_2	40.0
Tank	15.0
N_2	1.0
Tank and Plumbing	25.4
Autopilot	
Rate Gyro	2.0
Auto Attitude Components	11.5
Power	
Battery (rechargeable)	6.3
Circuitry	.6
Communications	
Radio – 2-way	1.0
Controller	2.5
Case and Miscellaneous Hardware	9.7

Furnishings	**2.9**
1. First Aid	1.9
Individual kits provided	
2. Personal	1.0

ECS Backpack System	✳	△	VAD
Service Module			
Top End Bill (0.040")	0.10		0.10
Static Inverter	3.00	-0.90	2.10
Filter	0.05		0.05
Marman Clamps	0.75		0.75
Blower	2.25	-1.00	1.25
Motor	3.00	-0.57	2.43
Adapter Plate	0.05		0.05
Heat Exchanger	3.00	-0.75	2.25
Water Separator	1.50		1.50
Miscellaneous	0.30		0.30
Connecting Hose	1.75		1.75

	✳	△	VAD
Batteries	13.25	-4.00	9.25
Supply Module			
Oxygen Pressure Regulator	0.50		0.50
Fill Connection	0.05		0.05
O_2 Shut-Off Valve	0.20		0.20
Pressure Transducer	0.15		0.15
O_2 Tank (empty)	2.50	-0.30	2.20
Water Tank (empty)	0.50		0.50
Marman Clamp	0.25		0.25
Absorbent Canister (empty)	0.50	-0.18	0.32
Water Valve	0.15		0.15
Piping	0.20		0.20
Expendables			
LOH Charcoal	1.2		1.2
Water (cold side)	2.0		2.0
O_2	0.5		0.5
Total	37.7	8.20	29.5

✳ Estimated weight proposed by Vendor "A" dated March 1962.

Based on subsequent studies, it is estimated that the weight reductions listed can be affected in the final design.

Seating and Restraint
_____

Requirements:

a. Position the two crewmen for optimum use of controls, displays and external vision.

b. Support and restrain the crewmen against the accelerations generated during a normal lunar descent, landing, launch and docking and provide leverage during zero "g".

c. Support and restrain the crewmen without injury against emergency landing impact up to the postulated destruction of the vehicle in the crew area.

Acceleration requirements were established as 7 earth "g" vertical for limit loads and 10 "g" for ultimate loads. Lateral and longitudinal accelerations were established as 0.6 times vertical "g" or 6 earth "g" ultimate.

Design Studies:

a. These requirements differ from aircraft type seats in that they were designed for 40−60 "g" longitudinal and 20-30 "g" vertical. Direct extrapolation would be misleading due to minimum gage requirements. Also, previous seats had been predominately bulkhead and floor mounted and these seats might be cantilevered from the floor.

b. Two types of seating that are least sensitive to minimum gage limitations were studied. They were, steel wire screen suspended on a tubular steel frame and aluminum honeycomb panels.

Steel wire screen appears most feasible for this application

Seat/Restraint System Weight	Pounds
Screen wire (steel)	(0.7)

Seat back	560 in^2 x .00047 lbs/in^2 =	.26
Pan	308 in^2 x .00145 lbs/in^2 =	.44

Tubular supports for fixed seat (steel)		(9.3)

Seat	.031 tubes,	107 in. x .0198 lbs/in. =	2.12
	.020	174 in. x .0129 lbs/in. =	2.24

Legs	.040	198 in. x .0252 lbs/in. =	5.00

Brazing, local gussets, and end fittings - estimated	(2.0)
Adjustment provisions (seat pan) guide link	(3.0)
Restraint provisions*	(5.0)
Weight per seat/restraint system	20.0

*Similar to:

Lap belt MS 22033	3.0 lbs.
Shoulder harness MS 16069	2.0 lbs.

17.3.3.11   Docking

Summary of weights substantiated:

LEM	100.0 lbs.
Command Module	352.5 lbs.

The purposes of this system are to facilitate the repositioning of the LEM from the engine side of the Service Module to the airlock end of the Command Module and to provide means for crew transfer between the LEM and the Command Module.

The docking system on the LEM is passive. It is comprised of a structure of 4 alignment tubes originating from the airlock door frame and projecting up and out at a 45° angle. These tubes are attached to the internal truss structure, which is utilized to redistribute the docking loads.

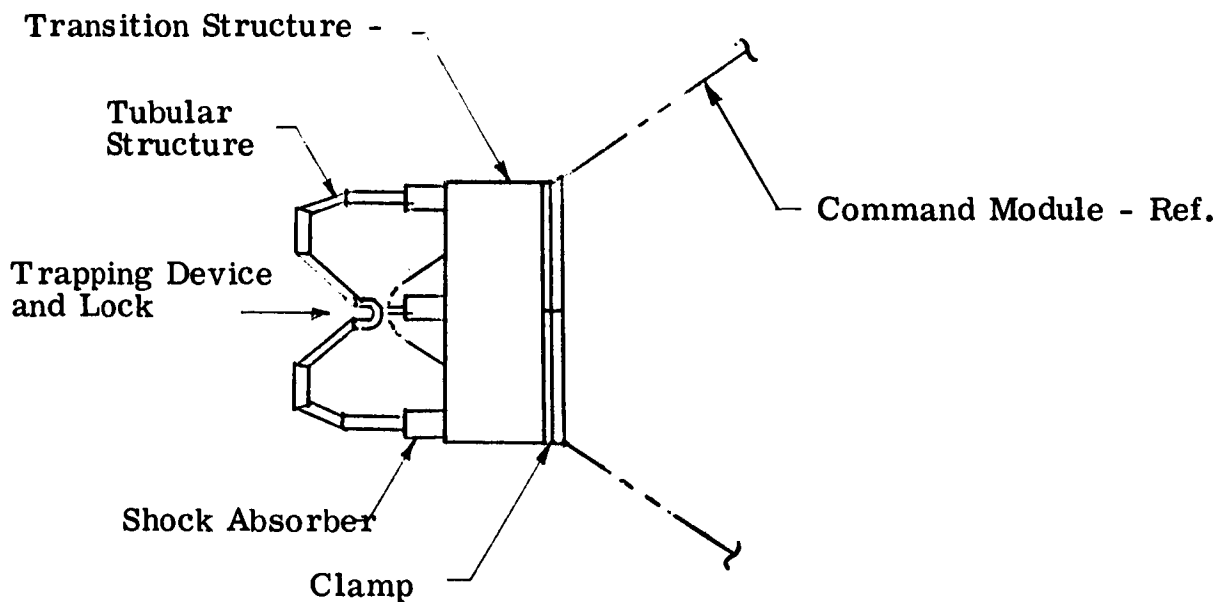Calculations are shown for the weights used.

LEM DOCKING STRUCTURE
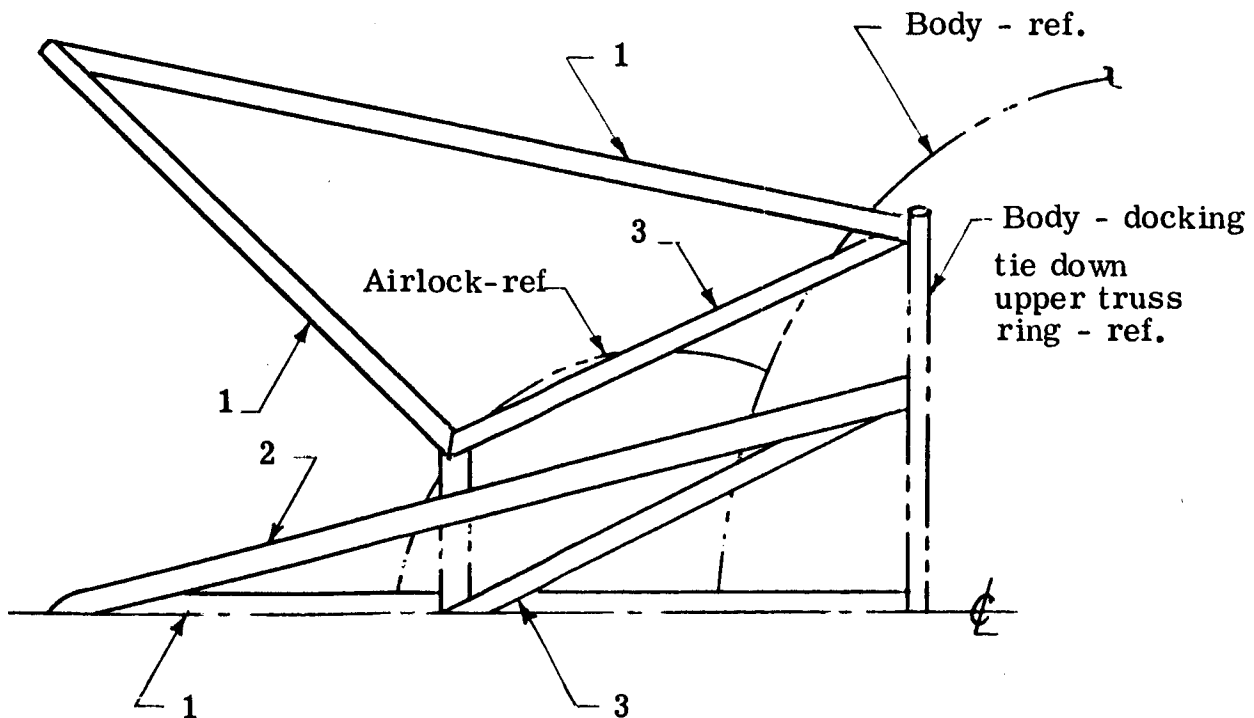
ALL STEEL CONSTRUCTION			LBS.
TUBE NO.	DIA.−WALL THICKNESS		
1	3 x .188	60 in. x .165 lbs/in. = 9.90 x 4 =	39.6
2	3 x .065	95 in. x .0595 lbs/in. = 5.65 x 8 =	45.2
3	1 3/8 x .035	59 in. x .0148 lbs/in. = 0.87 x 8 =	7.0
Misc.			8.2
TOTAL LEM DOCKING STRUCTURE			100.0

      The Command Module mounts the active portion of the docking system. A transition section which is inserted between the Launch Escape Propulsion System tower and the Command Module, houses the docking structure and lock release mechanism. It consists of a tubular structure designed to guide the mating vehicles together after initial contact. Shock mitigation is provided by 4 oil-type shock absorbers. A dual locking system is provided by the trapping device and pneumatically activated locking pins.

Transition Structure -

Tubular Structure

Command Module - Ref.

Trapping Device and Lock

Shock Absorber

Clamp

Docking System	lbs.
Transition Section and Clamp	(144.1)
Structure and Hardware (Aluminum semi-monocoque) 3.14×81 in. $\times 40$ in. $\times \dfrac{\text{ft.}^2}{144 \text{ in.}^2} \times 1.5 \dfrac{\text{lbs.}}{\text{ft.}^2}$	106.0
Clamp and Explosive Bolts 3.14×81 in. $\times .1$ lbs/in. $=$	25.4
Heating and Attachment Penalty - 50%	12.7
Shock Mitigation System	(52.0)
Oil Snubbers Est. 8.0 lbs. each $\times 4 =$	32.0
Latching Mechanism and Micro switches Est. 5.0 lbs. each $\times 4 =$	20.0
Pneumatic System	(20.0)
Air and Bottle 1,000 psi	10.0
Plumbing - lines, valves, clamps, etc.	10.0
Cartridge System - Pneumatic Backup	(2.0)
Structure (steel)	(72.6)
Tubes $3 \times .188$; 100 in. $\times .165$ lbs/in. $= 16.5$ lbs. $\times 4 =$	66.0
Hardware 10%	6.6
Propellant Penalty to Service Module	(25.0)
Miscellaneous (12%)	(36.8)
TOTAL DOCKING PENALTY TO COMMAND MODULE	352.5

17.3.3.12   Electronic Support System

Weight Summary:

ESS	26. 0 Lbs.
Built-in Test Equipment	18. 0
Input/Output Data Handling	8. 0
Displays and Controls	
Included in main display system	--
Computer	
Functions included in Navigation and Guidance	
computer	—

      The purpose of the Electronic Support System is to detect and to pinpoint malfunctions in all operations of the LEM. To accomplish this purpose, certain equipment and circuitry is built into the electronic systems. The detection scheme is routed through a computer and into appropriate read-out panels in the main display system, allowing control of the circuitry from a single source.

      The weights presented above are estimates based on the additional instrumentation required to monitor each function of all systems beyond that provided by the main Instrumentation system. Rather than provide separate (and heavier total weight) computers for the ESS and Navigation and Guidance Systems, it was estimated that the ESS function could be built into the guidance computers for 7. 0 pounds.

17. 3. 3. 13   Growth Allowance

          The history of aircraft weight growth has clearly shown
that the weight of an airplane increases substantially from the proposal
value, through preliminary design to the delivered article. Space vehicles
are experiencing the same, adverse weight trends.

          To prevent the spacecraft weight from exceeding the
launch vehicle capability, it is necessary to apply a reasonable "growth
allowance factor" in the proposal stage. Mercury weight growth data will
be most useful in determining such a growth allowance. The best available
data,plotted in Figure 17-7,illustrates the existing growth trend and justifies
the selected growth factor of 25%.

          In order to arrive at the actual number of pounds represented
by the 25% factor, it is first necessary to have a summary of all the
foregoing structure and systems weights. With reference to the Detail Weight
Breakdown, Section 17. 2. 1, the weight of the Crew Station   at the start of
the lunar landing phase is as follows:

Structure		987 lbs.
Systems		3518 lbs.
Crew Station	(without growth)	4505 lbs.
25% of 4505 lbs.		1126 lbs.
Crew Station	(with growth)	5631 lbs.

          The Propulsion Stage and Landing System are then sized
based on this weight, which automatically builds a contingency into the weight
of these systems. This approach seems reasonable since the Propulsion
and Landing Systems are direct functions of the weight of the Crew Station.

          The "funnel" shown in Figure 17-7 represents the fluctua-
tion of vehicle weight during the early phases of design. The significant point
illustrated by the funnel is that no matter how the weight fluctuates during
these phases, it must hit the 80% point at the beginning of design in order to
allow a growth of 25% through the remaining phases.

          To meet these objectives it is necessary to carry on a
stringent Weight Control Program, not only on this contractor's design
weights, but also on vendor furnished items. At the beginning of preliminary
design, detail target weights will be assigned to sub-assemblies, assemblies,
and installations. The goal is to meet or better the assigned target weights,
thus assuring that the overall LEM weight will be minimum. This program
is enhanced by a procedure for actual weighing of detail parts and sub-
assemblies thereby providing a check of manufacturing weight control. The
original target weights will also be verified through this procedure. A "total
team effort" concept for weight control will be brought into effect. That is,
not only the weight control specialists but all engineers assigned to the pro-
ject will be held responsible for achieving a light weight, accurately balanced
spacecraft.

          It is recommended that the lunar excursion module design
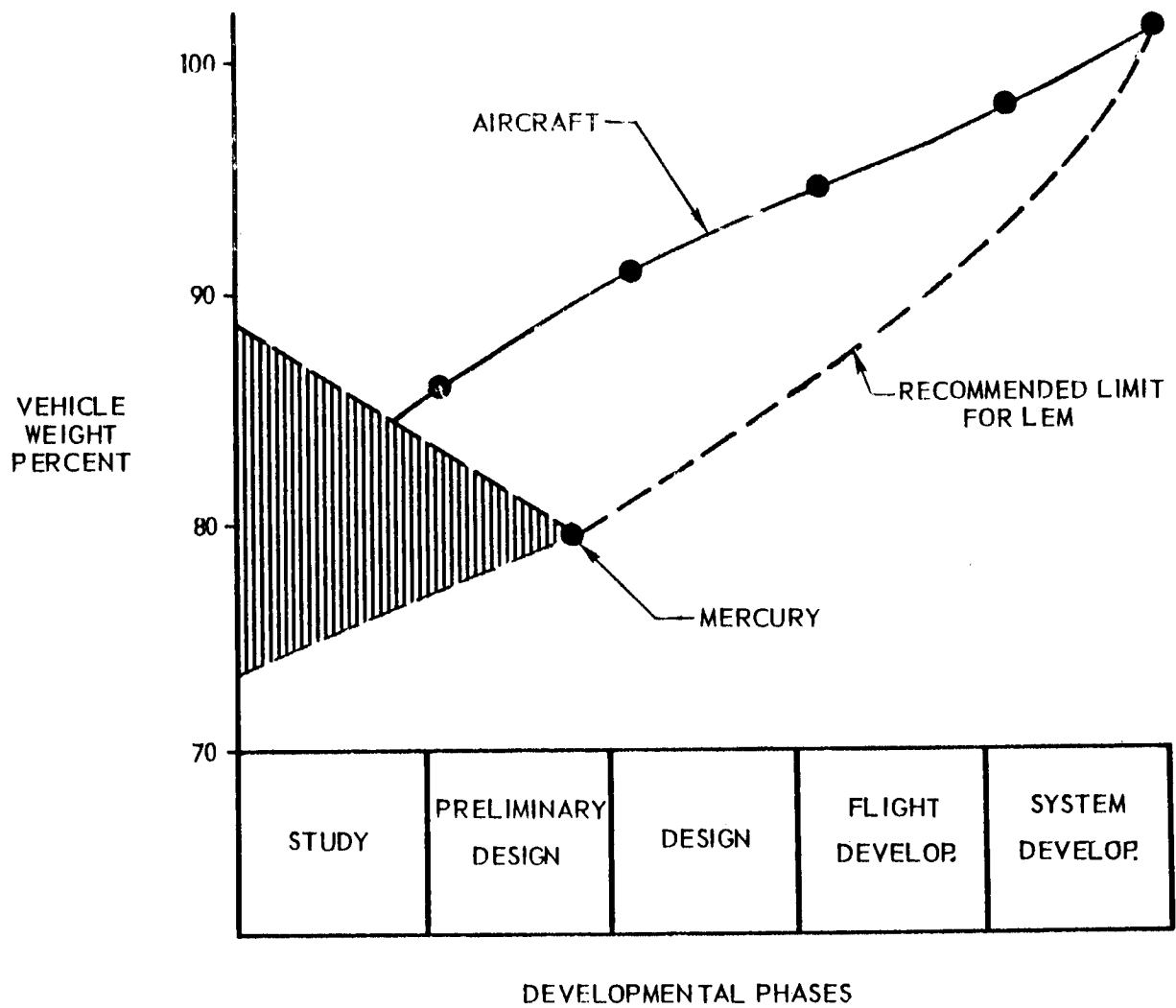provide for an anticipated weight growth, not to exceed 25%.

Figure 17–7 WEIGHT GROWTH HISTORY

17.3.4   Propulsion

The recommended LEM propulsion system is a pressure fed storable propellant system utilizing a gimballed cluster of three ablation cooled thrust chambers. Nitrogen tetroxide/aerozine-50 is the propellant chosen as representative of the desired class of storables. Propellant is consumed in an oxidizer to fuel ratio of 2:1.

The three ablation cooled thrust chambers are identical, each having a rated thrust of 6500 pounds, chamber pressures of 150 psia rated and 47 psia minimum and a nozzle expansion ratio of 20:1. Propellant is introduced into the chamber via a fixed area injector while a 3:1 throttle capability is accomplished by means of upstream throttle valves on each chamber.

Gimballing of the three-chamber cluster is provided in two planes by means of a double gimbal powered by redundant hydraulic actuator. Alignment is such that the thrust vector of the chamber cluster normally passes through vehicle c.g., regardless of which combination of chambers are operating. However, a thrust vector - c.g., misalignment capability of $\pm 5^o$ is provided for control purposes.

Propellant is stored in eight spherical titanium tanks, four of which are staged off on the lunar surface. All tanks are designed for 214 psia operating pressure. Thermal control is provided by means of reflective coatings on the staged tanks by .25 inches of multi-layer insulation on those which contain the ascent propellant and by a combination of insulation and electrical heaters on the feed lines.

Propellant pressurization is accomplished by four separate and independent systems utilizing unheated helium stored in spherical titanium tanks at 3000 psia. Each of the following groups of tanks are provided with a separate system with the two descent systems being staged off on the lunar surface:

(1) Descent fuel
(2) Descent oxidizer
(3) Ascent fuel
(4) Ascent oxidizer

A schematic of the recommended propulsion system is given in Section 6, Volume III.

Summary of weights substantiated:

		lbs. 23,288
L.E.M. PROPULSION		
Inert		2,122
Engines (3)		360
Gimbal & Truss		25
Gimbal Actuation		84
Lines, Fittings, Valves		110
Tanks and Supports		
Ascent	(4)	144
Descent *	(4)	338
Pressurization System		
Ascent	(2)	317
Descent *	(2)	744
Propellant		21,166
Consumed		
Ascent		(4,842)
Fuel		1,614
Oxidizer		3,228
Descent		(14,620)
Fuel		4,873
Oxidizer		9,747
Reserve (10% of Consumed)		
Ascent		(242)
Fuel		81
Oxidizer		161
Descent		(1,462)
Fuel **		487
Oxidizer ***		975

   *   Staged on Lunar surface prior to Ascent

  **   406 lbs. staged on Lunar surface prior to Ascent
       81 lbs. used as Ascent reserve

 ***   814 lbs. staged on Lunar surface prior to Ascent
       161 lbs. used as Ascent reserve

<u>ENGINES</u> <u>360</u>
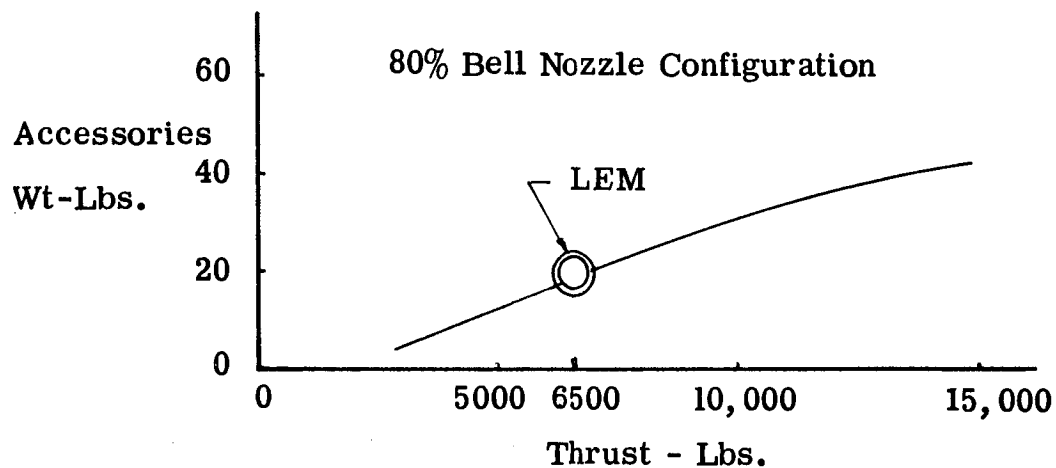
Engine Mounted Accessories (3) @ 20 lbs. each 60

Full Ablative Thrust Chamber (3) @ 100 lbs. each 300

<u>Engine Mounted Accessories</u>

80% Bell Nozzle Configuration

<u>Engine Mounted Accessories - Wt. Per Engine</u> (20.0)

Propellant Feed System 20.0 lbs. x .625 12.5

Gimbal and Actuators 20.0 lbs. x .210 4.2
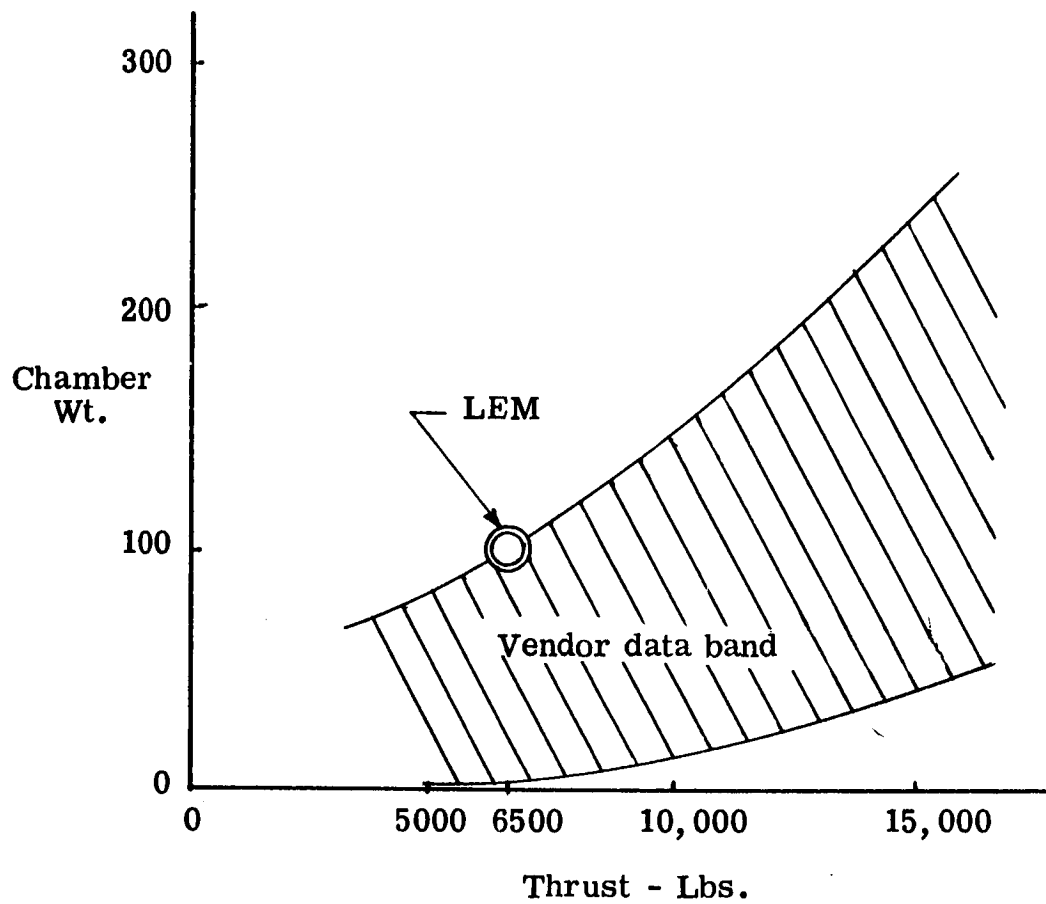
Electrical System 20.0 lbs. x .165 3.3

$\overline{1.000}$

(The percentage breakdown is based on vendor data)

Full Ablative Thrust Chamber

selected weight = 100 lbs. each of 3 required

GIMBAL AND TRUSS   25.0

       Member A, 1 7/8 x .049 al. - .0284 $\frac{lbs.}{in.}$ x 28 in. x 3   2.39

       Member B, 1 x .049 al. - .0147 $\frac{lbs.}{in.}$ x 16 in. x 3   0.71

       Corner Joints   3 lbs. x 3   9.00

       Center Point Casting   3.00

       Gimbal   4.00

       Misc.   5.90

Plan View   Profile View
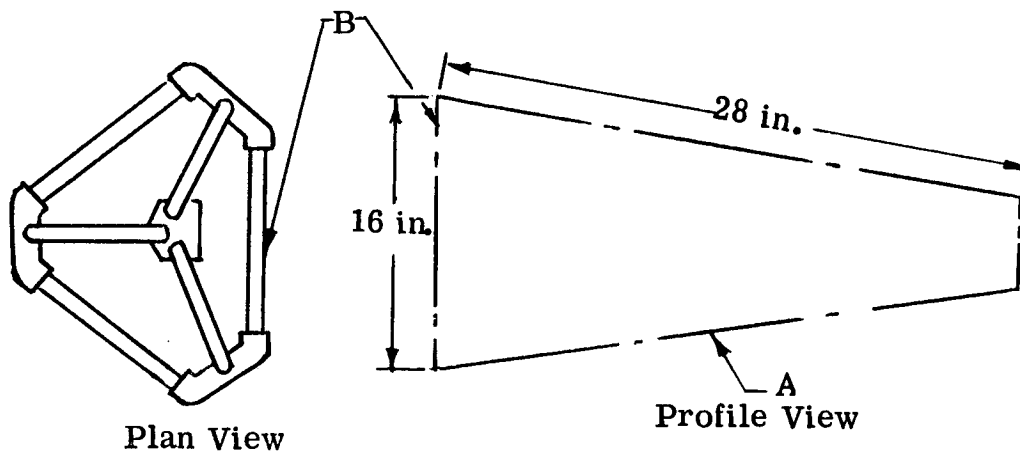
GIMBAL ACTUATION   84.0

   1)   Integrated Pump. Assembly   (2)   43.0

   2)   Accumulator   (2)   10.0

   3)   Actuator (dual parallel)   20.0

   4)   Plumbing (parallel system)   11.0

(See details next page)

GIMBAL ACTUATION - details

1. <u>Integrated Pump Assembly</u> - each   (21.5) lbs.

   Based on 2 $HP_{avg.}$ for 15 minutes; with ref. to the Vickers Co.

   Bulletin, A-5239, this assembly includes the following:

   Batteries

fixed	variable	
$\left(\dfrac{1\ lb.}{HP} \times 2\ HP\right)$	$+\left(\dfrac{15\ lb.}{HP\ Hr.} \times 2\ HP \times \dfrac{15\ min.}{60\ min./hr.}\right)$	$=$ 9.5

   Drive Motor

   $$\frac{4\ lb.}{HP} \times 2\ HP = \qquad\qquad 8.0$$

   Hydraulic Pump + Reservoir + Fluid + Valves + Instal.

   $$\frac{2\ Lb.}{HP} \times 2\ HP = \qquad\qquad 4.0$$

   Above is similar to the one designed and built for MINUTEMAN

2. <u>Accumulators</u> - each   Est.   (5.0) lbs.

   These have been added to the basic system to minimize
   the over-all weight which could result from control system
   requirements due to the large peak loads.

   50 in.^{3} accumulator

3. <u>Actuators</u> - each   Est.   (10.0) lbs.

   Peak Moment = 2230 ft.-lbs.

   Max. Hydraulic Pressure = 2400 psi.

   Piston Area = 0.6 in.^{2}

   Required Moment Arm:

   $$1_A = \frac{2230\ ft\text{-}lbs.}{0.6\ in.^2 \times 2400\ lbs/in.^2} = 1.55\ ft.$$
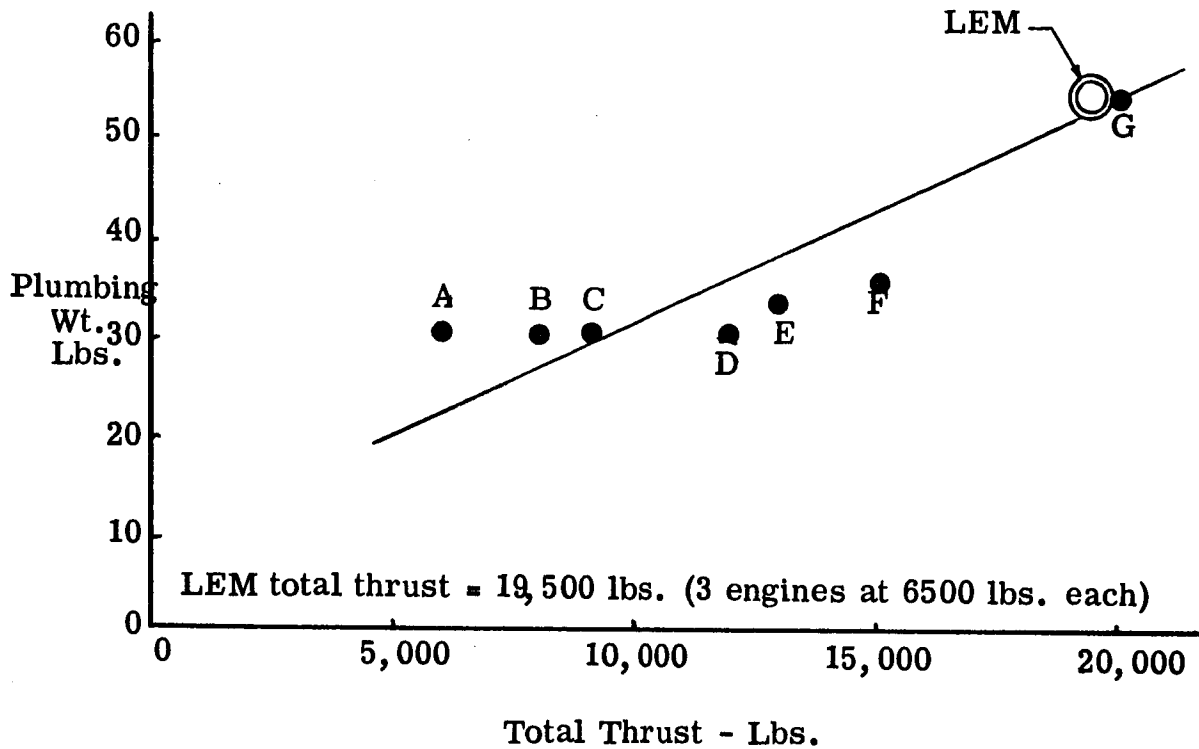
   Stroke: = 2 x 1.55 ft. x .0875 = .27 ft. = 3.25 in.

LINES, FITTINGS, VALVES, REGULATORS, ETC.: PLUMBING   110.0

Plumbing required x 2 for redundancy

LEM total thrust = 19,500 lbs. (3 engines at 6500 lbs. each)

Total Thrust - Lbs.

TANKS AND SUPPORTS   482.0

Ascent (contain Ascent Consum. & Reserve + Descent Res.)		(144.0)
Fuel	(2)	62.0
Oxidizer	(2)	82.0
Descent (Contain Descent Consumed only)		(338.0)
Fuel	(2)	146.0
Oxidizer	(2)	192.0

(See details, next page)

Ascent

Fuel Tank (6 Al. 4V Titanium) and Supports

Fuel Wt. = 1091.0 lbs. per tank

Vol. = $1091 \times \dfrac{ft.^3}{55.4 \text{ lbs.}}$ = 19.70 ft.^{3} $\times$ 1.05 = 20.7 ft.^{3}

Dia. of Sphere = $(1.91 \times Vol.)^{1/3}$ = 3.4 ft. = 40.8 in.

Area of Sphere = $3.14 \times (3.4)^2$ = 36.3 sq. ft.

= 5220 sq. in.

$t_{wall} = \dfrac{\Delta P \times Dia. \times F.S.}{4\, Ft_y} = \dfrac{200 \times 40.8 \times 2}{4 \times 160,000} = .0255$ in.

Shell Wt. of spherical tank = 5220 in.^{2} $\times$ .0255 in. $\times$ .160 $\dfrac{lbs.}{in.^3}$ = 21.3

Support Wt. = 25% of Shell Weight =   5.3

Baffle, Weld, and Manufact. Variation Allow. = 15% of Shell Wt. = 3.2

Misc. = .12% of Tank + Fuel Weight =   1.3

      Total Tank and Support Wt., Each of (2)   31.1 lbs.

Ascent

Oxidizer Tank (6 Al. 4V Titanium) and Supports

Oxidizer Wt. = 2182.0 lbs. per tank

Vol. = $2182.0 \times \dfrac{ft.^3}{87.4 \text{ lbs.}}$ = 25.0 ft.^{3} $\times$ 1.05 = 26.2 ft^3

Dia. of sphere = $(1.91 \times Vol.)^{1/3}$ = 3.68 ft. = 44.2 in.

Area of sphere = $3.14 \times (3.68)^2$ = 42.5 ft.^{2}

= 6150 in.^{2}

$t_{wall} = \dfrac{200 \times 44.2 \times 2}{4 \times 160,000}$ = .0276 in.

Shell Wt. = 6150 in.^{2} $\times$ .0276 in. $\times$ .160 $\dfrac{lbs.}{in.^3}$ 27.2

Support Weight = 25% of Shell Weight =   6.8

Baffle, etc. = 15% of Shell Weight =   4.1

Misc. = .12% of Tank + Oxidizer Weight =   2.7

       Total Tank and Support Wt., Each of (2)   40.8 lbs.

   Descent

Fuel Tank (6 Al. 4 V Titanium) and Supports

Fuel Wt. = 2436.5 lbs.

Vol. = $2436.5 \times \dfrac{ft.^3}{55.4 \ lbs.} = 44.0 \ ft.^3 \times 1.05 = 46.2 \ ft^3$

Dia. of Sphere = $(1.91 \times 46.2)^{1/3} = 4.45$ ft. = 53.5 in.

Area = $3.14 \times (4.45)^2 = 62.2 \ ft.^2 = 8950 \ in.^2$

$t_{wall} = \dfrac{200 \times 53.5 \times 2}{4 \times 160,000} = .0335$ in.

Shell Wt. = 8950 in.^{2} x .0335 in. x .160 $\dfrac{lbs.}{in.^3}$ =   47.9

Support Wt. = 25% of Shell Weight =   12.0
Baffle, etc. = 15% of Shell Weight =   7.2
Misc. = .25% of Tank + Fuel Weight =   5.8

       Total Tank and Support Wt., Each of (2)   72.9 lbs.

   Descent

Oxidizer Tank (6 Al. 4 V Titanium) and Supports

Oxidizer Wt. = 4873.5 lbs.

Vol. = $4873.5 \times \dfrac{ft.^3}{87.4 \ Lbs.} = 55.8 \ ft.^3 \times 1.05 = 58.65 \ ft^3$

Dia. of Sphere = $(1.91 \times 58.7)^{1/3} = 4.81$ ft. = 57.7 in.

Area = $3.14 \times (4.8)^2 = 72.7 \ ft.^2 = 10,480 \ in.^2$

$t_{wall} = \dfrac{200 \times 57.7 \times 2}{4 \times 160,000} = .0361$ in.

Shell Wt. = 10,480 in.^{2} x .0361 in. x .160 $\dfrac{lbs.}{in.^3}$ =   60.5

Support Weight = 25% of Shell Weight =   15.1

Baffle Weight = 15% of Shell Weight =   9.1

Misc. = .25% of Tank + Oxidizer Weight =   11.3

    Total Tank and Support Wt., Each of (2)   96.0 lbs.

PRESSURIZATION SYSTEM   1061.0 lbs.

  Ascent   (317.0)

    Tanks   297.0

    Helium   20.0

  Descent   (744.0)

    Tanks   696.4

    Helium   47.6

Ascent

Tanks and Supports (6 Al. 4 V Titanium)

To Pressurize Fuel

Helium Wt. = 8.8 lbs.

$$Vol. = \frac{8.8 \times ft.^3}{1.7\ lbs.} = 5.2\ ft.^3 \times 1.05 = 5.5$$

Dia. of Sphere = $(1.91 \times 5.5)^{1/3}$ = 2.19 ft.   = 26.3 in.

Area = $3.14 \times (2.19)^2$ = 15.1 ft^2 = 2170 in.^{2}

$$t_{wall} = \frac{3000 \times 26.3 \times 2}{4 \times 160,000} = .246\ in.$$

Shell Wt. = 2170 in.^{2} x .246 in. x .160 $\frac{lbs.}{in.^3}$ =   85.7

Support Wt. = 25% of Shell Weight =   21.4

Weld, Manufact. Var. Allow. = 15% of Shell Weight =   12.9

Misc. = 2% of Tank + Helium =   2.5

    Total Tank and Support Weight   122.5 lbs.

Ascent

Tanks and Supports (6 Al. 4 V Titanium)

To Pressurize Oxidizer:

Helium Wt. = 11.12 lbs.

$$Vol. = 11.12 \times \frac{ft.^3}{1.7 \; lbs.} = 6.55 \; ft^3 \times 1.05 = 7.85 \; ft^3$$

Dia. of Sphere = $(1.91 \times 7.9)^{1/3}$ = 2.46 ft. = 29.6 in.

Area = $3.14 \times (2.46)^2$ = 19.05 ft.^{2} = 2740 in.^{2}

$$t_{wall} = \frac{3000 \times 29.6 \times 2}{4 \times 160,000} = .278 \; in.$$

Shell Wt. = 2740 in.^{2} × .278 in. × .160 lbs./in.^{3} =   122.0

Support Wt. = 25% of Shell Weight =	30.5
Weld, Manufact. Var. Allow. = 15% of Shell Wt. =	18.3
Misc. = 2% of Tank + Helium Wt. =	3.6

Total Tank and Support Weight   174.4 lbs.

Descent

Tanks and Support (6 Al. 4 V Titanium)

To Pressurize Fuel:

Helium Wt. = 21.2 lbs.

$$Vol. = 21.2 \times \frac{ft.^3}{1.7 \; lbs.} = 12.5 \; ft.^3 \times 1.05 = 13.10 \; ft^3$$

Dia. of Sphere = $(1.91 \times 13.10)^{1/3}$ = 2.92 ft. = 35.10 in.

Area = $3.14 \times (2.92)^2$ = 26.8 ft.^{2} = 3860 in.^{2}

$$t_{wall} = \frac{3000 \times 35.10 \times 2}{4 \times 160,000} = .329 \; in.$$

Shell Wt. = 3860 in.^{2} × .329 in. × .160 lbs./in.^{3} =   204.0

Support Wt. = 25% of Shell Wt. =	51.0
Weld, Manufact. Var. Allow. = 15% of Shell Wt. =	30.6
Misc. Internal = 4% of Tank + Helium Wt. =	12.3
Misc. External Support	11.0

Total Tank and Support Weight   308.9 lbs.

Descent

Tanks and Support (6 Al. 4 V Titanium)

To Pressurize Oxidizer:

Helium Wt. $= 26.4$ lbs.

Vol. $= 26.4 \times \dfrac{ft.^3}{1.7\ lbs.} = 15.6$ ft.$^3 \times 1.05 = 16.30$ ft^3

Dia. of Sphere $= (1.91 \times 16.30)^{1/3} = 3.15$ ft. $= 37.8$ in.

Area $= 3.14 \times (3.15)^2 = 31.2$ ft.$^2 = 4500$ in.^{2}

$t_{wall} = \dfrac{3000 \times 37.8 \times 2}{4 \times 160,000} = .355$ in.

Shell Wt. $= 4500$ in.$^2 \times .355$ in. $\times .160$ lbs./in.$^3 =$	256.0
Support Wt. $= 25\%$ of Shell Wt. $=$	64.0
Weld, Manufact. Var. Allow. $= 15\%$ of Shell Wt. $=$	38.4
Misc. Internal $= 4\%$ of Tank + Helium Wt. $=$	15.4
Misc. External Support	13.7
Total Tank and Support Weight	387.5 lbs.

    A statistical plot has also been made to show the comparison between the Apollo Service Module and the LEM pressurization systems. The system weight difference indicated in the first plot is clearly attributed to the tankage weight which is conservative in LEM.

PRESSURIZATION SYSTEM WT. COMPARISON
TOTAL SYSTEM
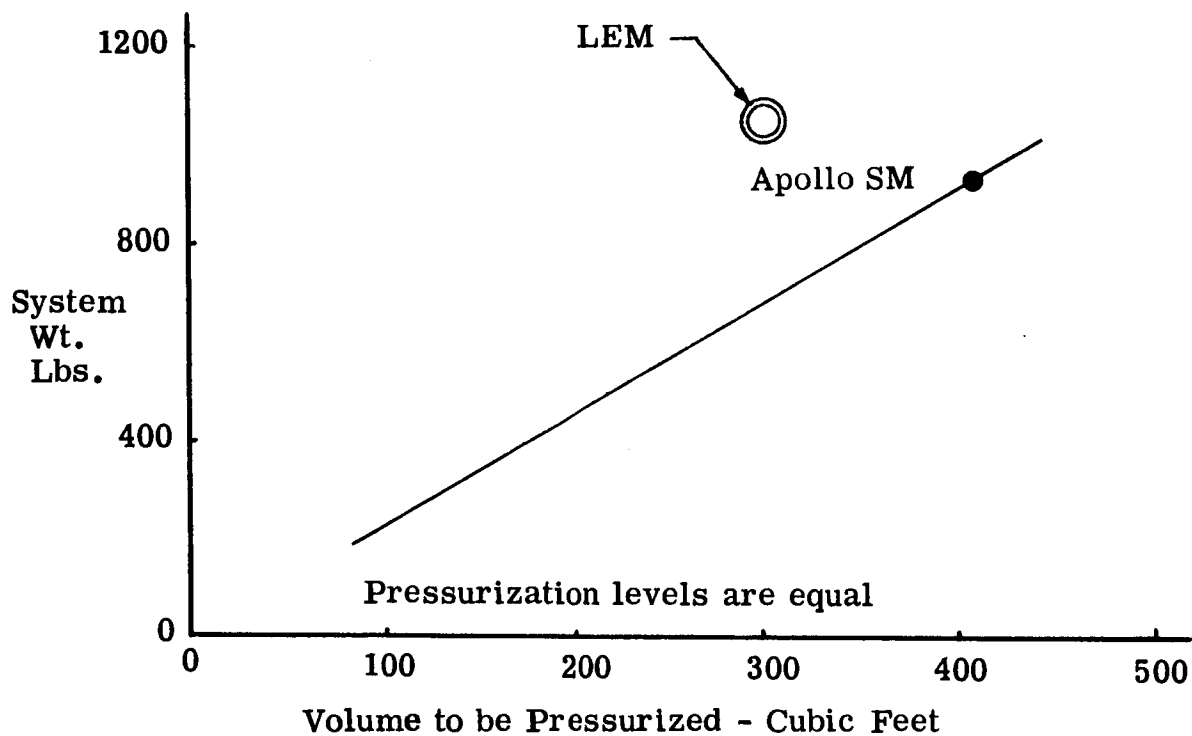
Pressurization levels are equal

Volume to be Pressurized – Cubic Feet

HELIUM WEIGHT

Volume to be Pressurized – Cubic Feet

TANK WEIGHT

Volume to be Pressurized - Cubic Feet
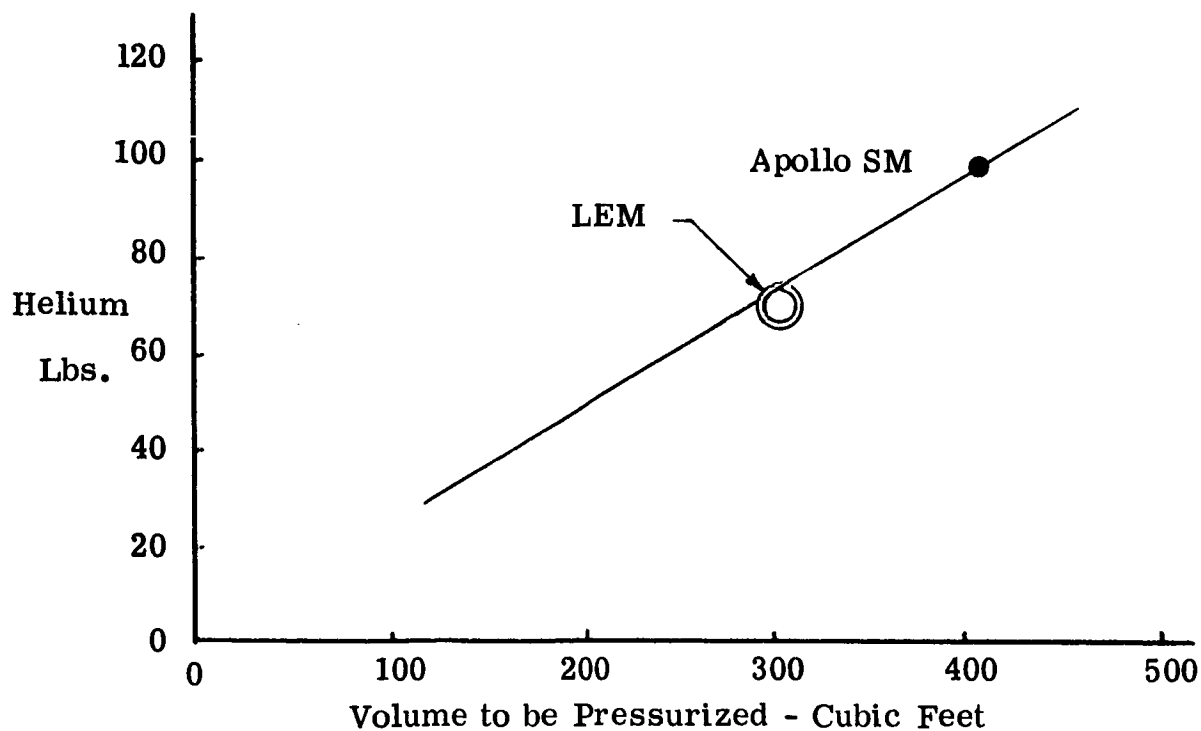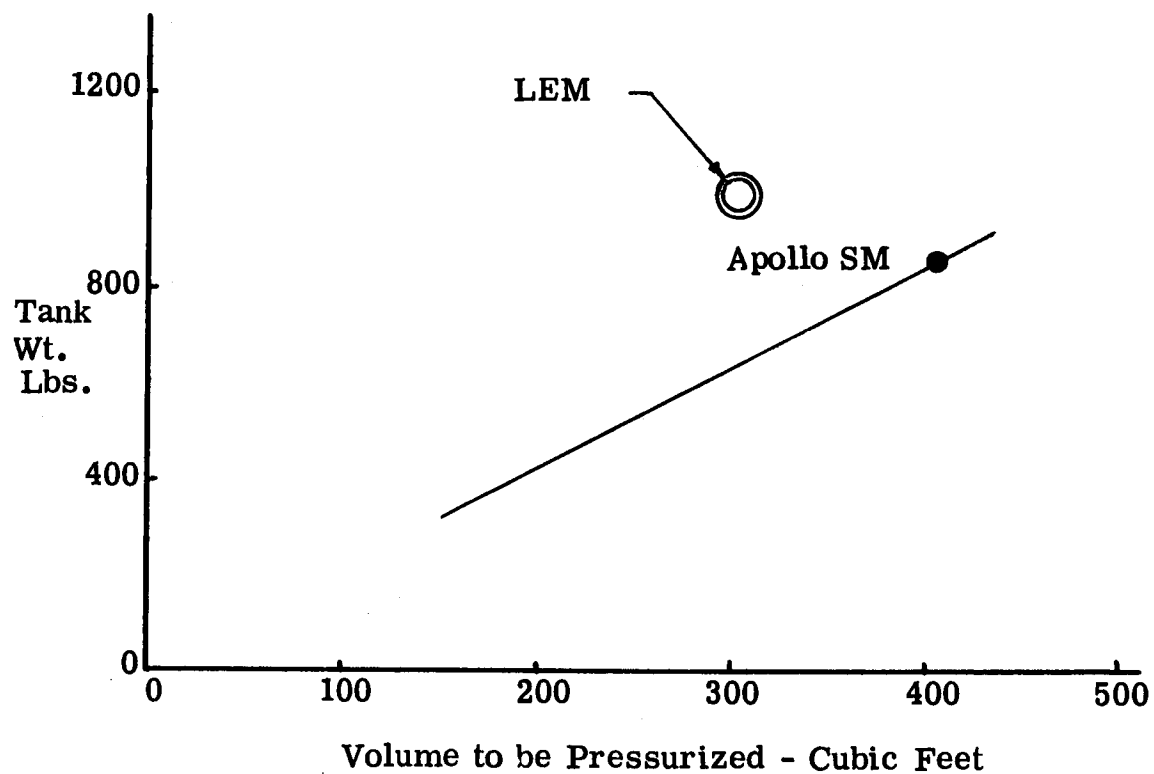
Propellant

Detail calculations showing propellant consumed and reserve are presented in Appendix E to the Propulsion Section, 6.0, Volume III.

17.3.5   Landing System

Summary of weights substantiated:

LANDING SYSTEM	975.0 lbs.
Main Support Members	489.4
Web	32.0
Feet	322.4
Support Tube - Main Ring	80.0
Release Mechanism	40.0
Misc.	11.2

The landing system shown in Figure 17-8 must provide a "soft", stable, landing of the LEM under all anticipated conditions of lunar surface, environment, and landing events. The landing system also serves as the launch pad for the ascent phase of the mission. After LEM has come to rest on the lunar surface, the release mechanisms are actuated and the Crew Station with attached propulsion, sits in the landing system. At lunar launch, the landing system and all gear (descent tanks, fuel cells, etc.) attached to it are "staged" on the lunar surface.

To save weight, a four-foot design is employed rather than a tripod arrangement. Each foot has swiveling capability, incorporated to avoid "tripping" over obstacles. The foot is a flat-bottomed pan of 4130 steel with 45° sloped sides covered with "Stafoam 603" (6 pounds per cubic foot density) to minimize abrasion damage. Attached to the foot is an energy absorber piston used in conjunction with a system of leaf springs to provide restoration to the neutral position.

Materials and gages shown in the detail weight calculations are results of structural analysis of the configuration presented. A statistical comparison of landing gear weights was also made. The deviation of the HS-625 point from the trend was expected. The extreme length required for landing stability drastically increases the weight of the gear.
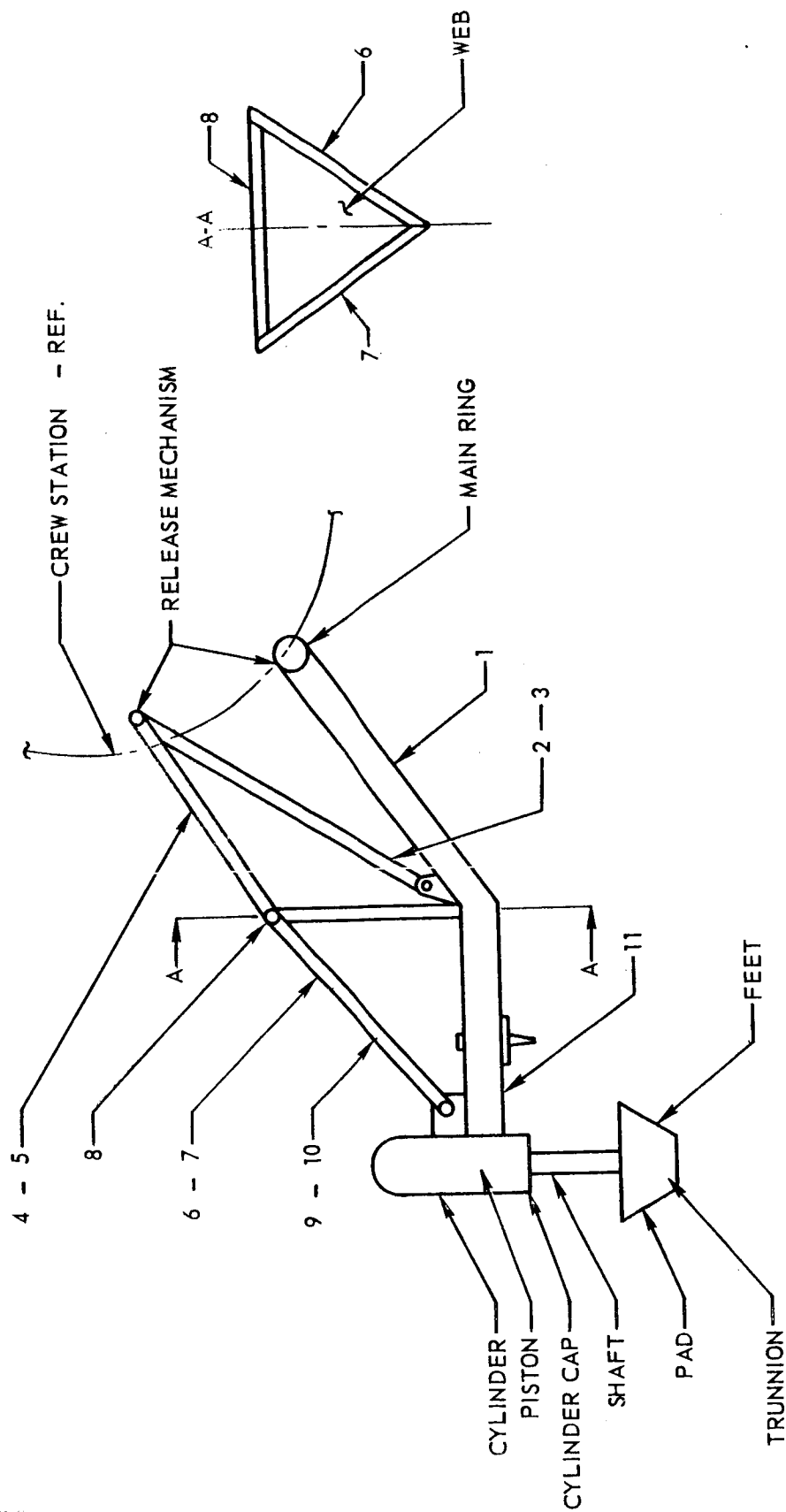
Figure 17-8 LANDING SYSTEM

| LANDING SYSTEM						975.0 lbs.
Member	Length	Mat'l.	Wt/Inch	Weight	Req'd	Wt. – Lbs.
1	84.5	7075-T6	.28	24.00	4	96.0
2 & 3	125.0	2024-T6	.149	18.65	8	149.2
4 & 5	84.0	2024-T6	.0965	8.10	8	64.8
6 & 7	51.0	2219-T31	.0281	1.44	16	23.0
8	48.0	2219-T31	.0281	1.35	8	10.8
9 & 10	87.0	2024-T3	.0965	8.40	8	67.2
11	70.0	7075-T6	.28	19.60	4	78.4

Web   2219-T31 $.032 \text{ in.} \times 1250 \text{ in.}^2 \times \dfrac{.1 \text{ lbs.}}{\text{in.}^3} = 4 \times 8$ 32.0

Feet

Shaft	16.6 x 4	66.4
Piston	2.0 x 4	8.0
Cylinder Cap	3.4 x 4	13.6
Pad	35.6 x 4	142.4
Cylinder and Balsa	17.0 x 4	68.0
Trunion	6.0 x 4	24.0

Support Tube - Main Ring 7075-T6 Forg.
$.252 \text{ lbs/in.} \times 3.14 \times 100 =$ 80.0

Release Mechanism   40.0

Misc. Hdw.   11.2

STATISTICAL COMPARISON

LANDING SYSTEM WEIGHT IN PERCENT OF LANDED WEIGHT
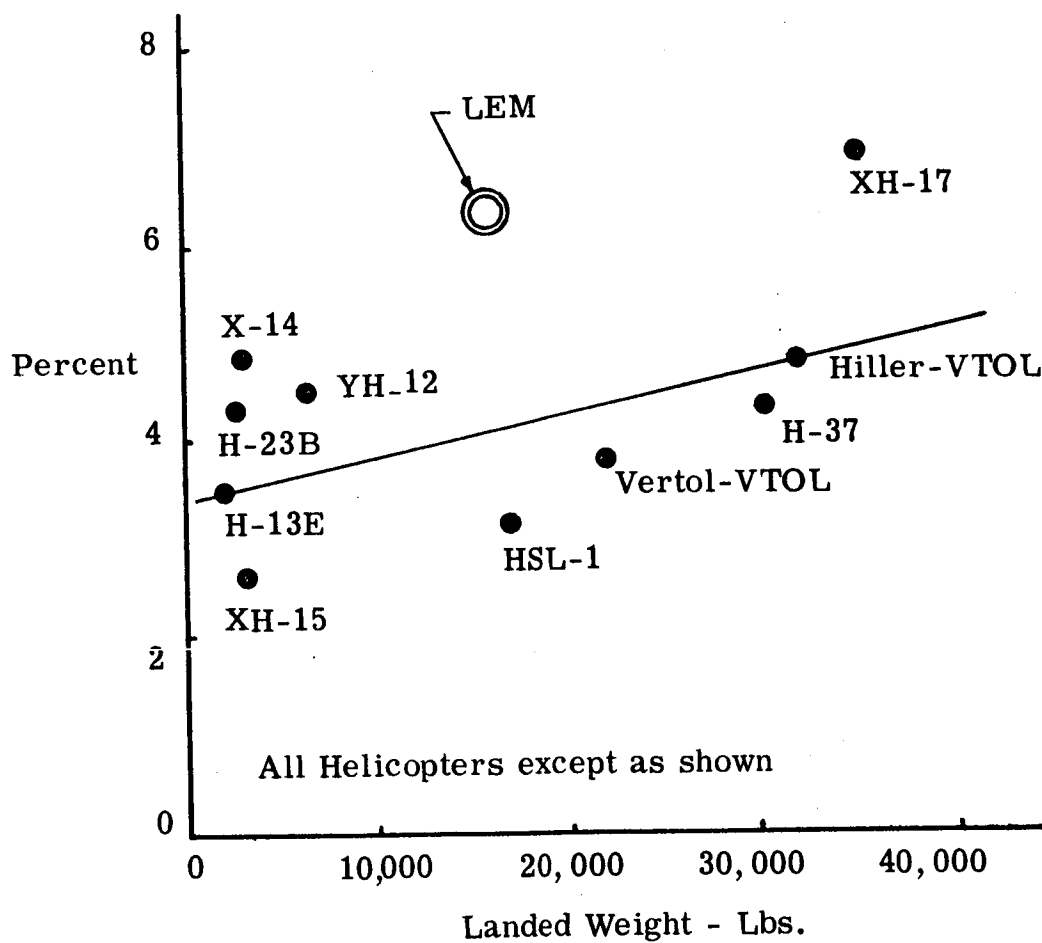
17.3.6   Adapter/Fairing and Launch Vehicle Support Structure

Summary of weights:

	Pounds
Adapter/Fairing	3230.0
Launch Vehicle Support Structure	559.0

17.3.6.1   Adapter Fairing

The main functions of this structure are:

(1)   To provide a structural interconnect between the Apollo and the Launch Vehicle.

(2)   To provide protection for the LEM from micrometeorites during the initial part of the trajectory.

(3)   To provide heat protection for the LEM during the earth-boost phase.

Considering the relatively high aerodynamic boost loadings and the large shell radius, resistance to cylindricial buckling can be provided by sandwich construction for less weight than by other schemes. The following weight calculations are based on brazed stainless steel honeycomb.

Adapter/Fairing   3230 Lbs.

◄— Command Module, ref.   S-IVB, ref. —►
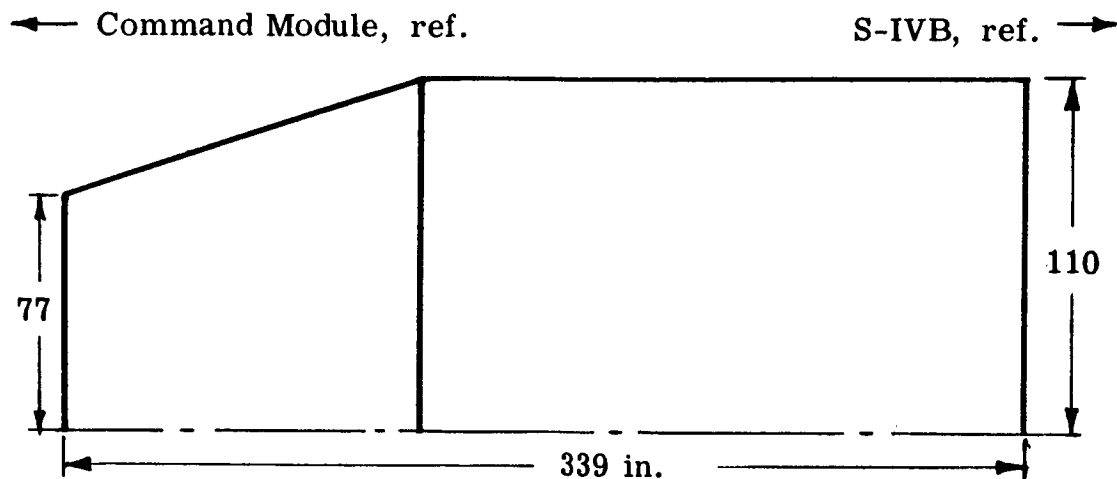
Surface Area

$$\frac{.5 \ (3.14 \times 154 + 3.14 \times 220) \ 127 + 3.14 \times 220 \times 216}{144} = 1554 \ \text{sq. ft.}$$

Shell

.012 Faces	15-7 ph stainless steel	1.08	
.7 Core	6 lbs./ft.^{3}	.35	
Braze Alloy		.13	
	Unit Weight	1.56 lbs/ft^2	

Wt.=1554 sq. ft. x 1.56 lbs./sq. ft. =   2424

End Frames   180

Center Frames   150

Separation Band   50

Peripheral Splices   90

Longitudinal Splices   336

17.3.6.2   Launch Vehicle Support Structure

The weight for this item does not appear in the Spacecraft Weight Summary since it is considered a part of the Launch Vehicle.

This structure is supported from the forward face of the S-IVB Launch Vehicle. Boost acceleration loads are transmitted through the existing Lunar Landing Gear truss and related attaching structure of the LEM. A truss framework at the forward end of the booster distributes the four concentrated loads from the LEM landing system-booster attaching trunnions to the monocoque shell of the S-IVB Launch Vehicle.

Launch Vehicle Support Structure		5590 Lbs.

Honeycomb Shell

.025 in. faces   0.72

.75 in. core 5 lbs/cu. ft.   0.31

Bond   0.26

Unit Weight = 1.29 lbs/ft.^{2}

Area = $\pi \cdot D_{avg} \cdot L = \dfrac{3.14 \times 200 \times 35}{144} = 153$ ft.^{2}

Wt. = 1.29 lbs/ft.^{2} x 153 ft.^{2} =   197.0

Longitudinal Splice - Honeycomb Shell   (4)   5.0

Lower Attach Joint

Area Req'd. = .86 in.^{2}

Wt. = 3.14 x 220 x .86 x .1 lbs./in.^{3} =   59.5

Attach Arms

1) Axial Load Members - 4 req'd.

Upper - avg. area = 2.5 in.^{2}

Lower - avg. area = 1.25 in.^{2}

Wt. $= (15 \text{ in.} \times 2.5 \text{ in.}^2) + (35 \text{ in.} \times 1.25 \text{ in.}^2) = 81.25 \text{ in.}^3$

$81.25 \text{ in.}^3 \times .1 \text{ lbs/in.}^3 \times 1.25 \times 4 =$ 40.6

2) Side Arms - 8 required

    Upper - avg. area $= 1.81 \text{ in.}^2$

    Lower - avg. area $= .91 \text{ in.}^2$

    Wt. $= \left[(21.2 \text{ in.} \times 1.81 \text{ in.}^2) + (35 \text{ in.} \times .91 \text{ in.}^2) \right] .1 \times 8 =$ 56.0
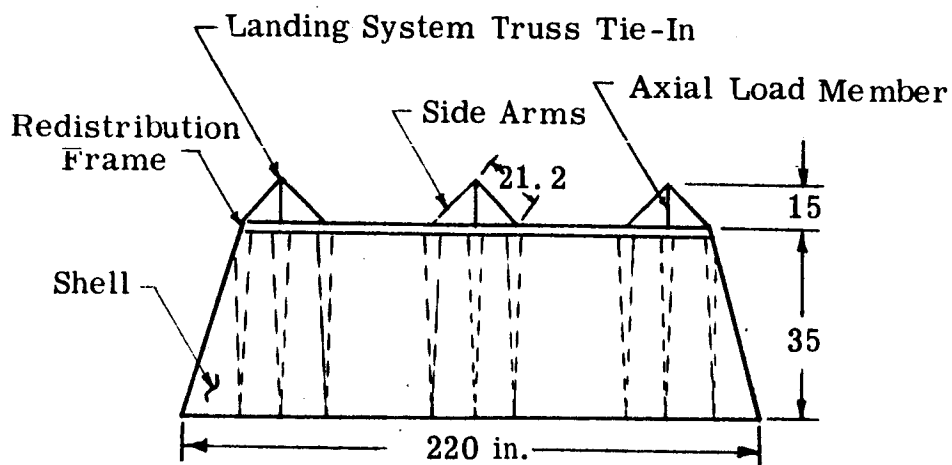
3) Joints   10.0

Upper Redistribution Frame

    Area Req'd $= 2.9 \text{ in.}^2$

    Wt. $= 3.14 \times 180 \text{ in.} \times 2.9 \text{ in.}^2 \times \dfrac{.1 \text{ lbs.}}{\text{in.}^3} =$ 164.0

Misc. 5%   26.9

S-IVB

17.4   WEIGHT STUDIES

A series of investigations were carried out to explore the full range of LEM concepts. It is desirable to know the effect of the following parameters on the weight of the LEM.

(1) Storable vs. cryogenic propellant
(2) Crew size; 1 man vs. 2
(3) Mission duration
(4) Hot side vs. cold side operation
(5) Staging

Results of the studies made have been summarized and are presented in graph form in Section 17.3.1. Basic data on a few of the concepts investigated are tabulated in summary form and presented in Table 17-IV.

17.4.1   Parametric Studies

Storable vs Cryogenic Propellants
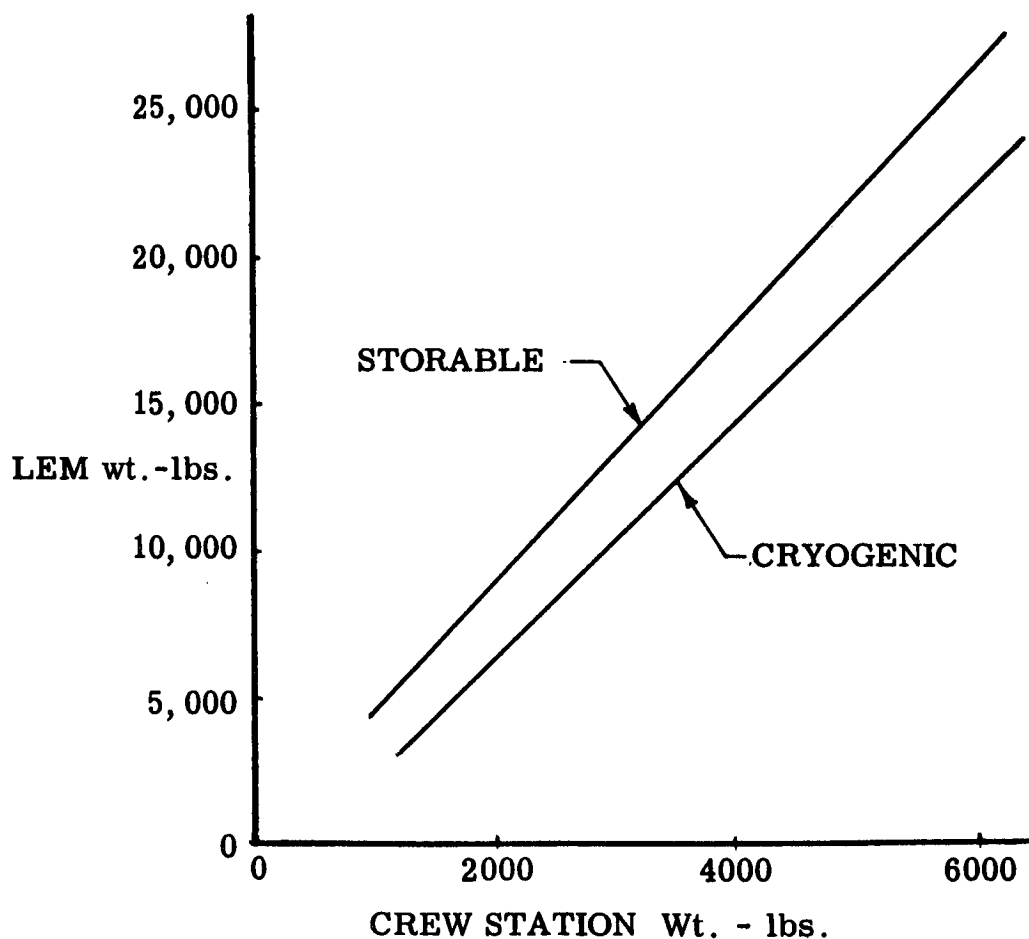
Storable concepts are 30-40% heavier than Cryogenic concepts

Crew Size
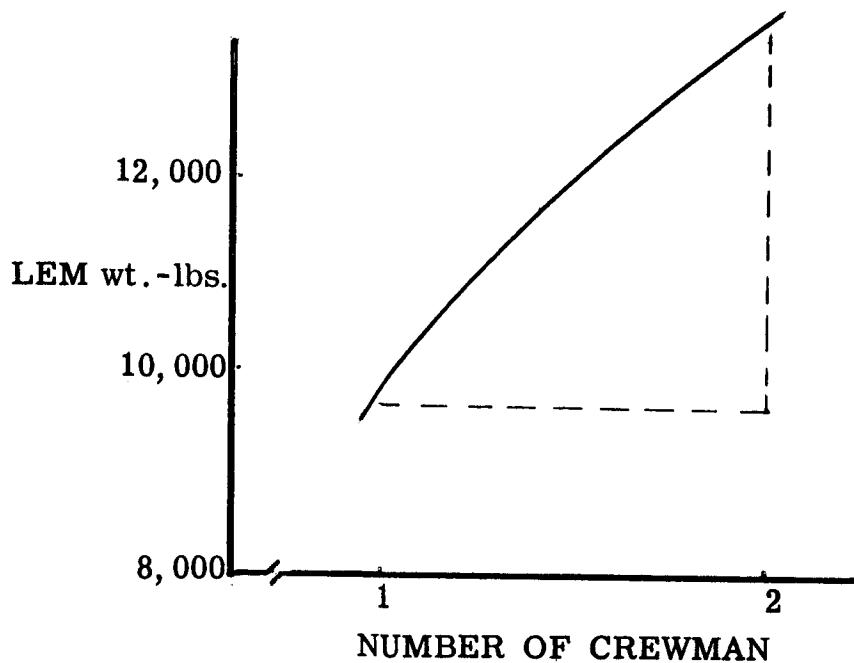
The addition of one man and his associated equipment (suit, seat, SMU, food and water) contributes approximately 400 pounds to the basic weight of the Command Capsule. This in turn increases the structural size of the capsule and imposes an additional requirement on the Environmental Control System, Electrical Power and Reaction Control systems. These basic weights, carried to and from the lunar surface, cause the propulsion stage to grow. The weight difference between the two plotted points is, therefore, a total LEM change.

Mission Duration

MISSION DURATION - Days
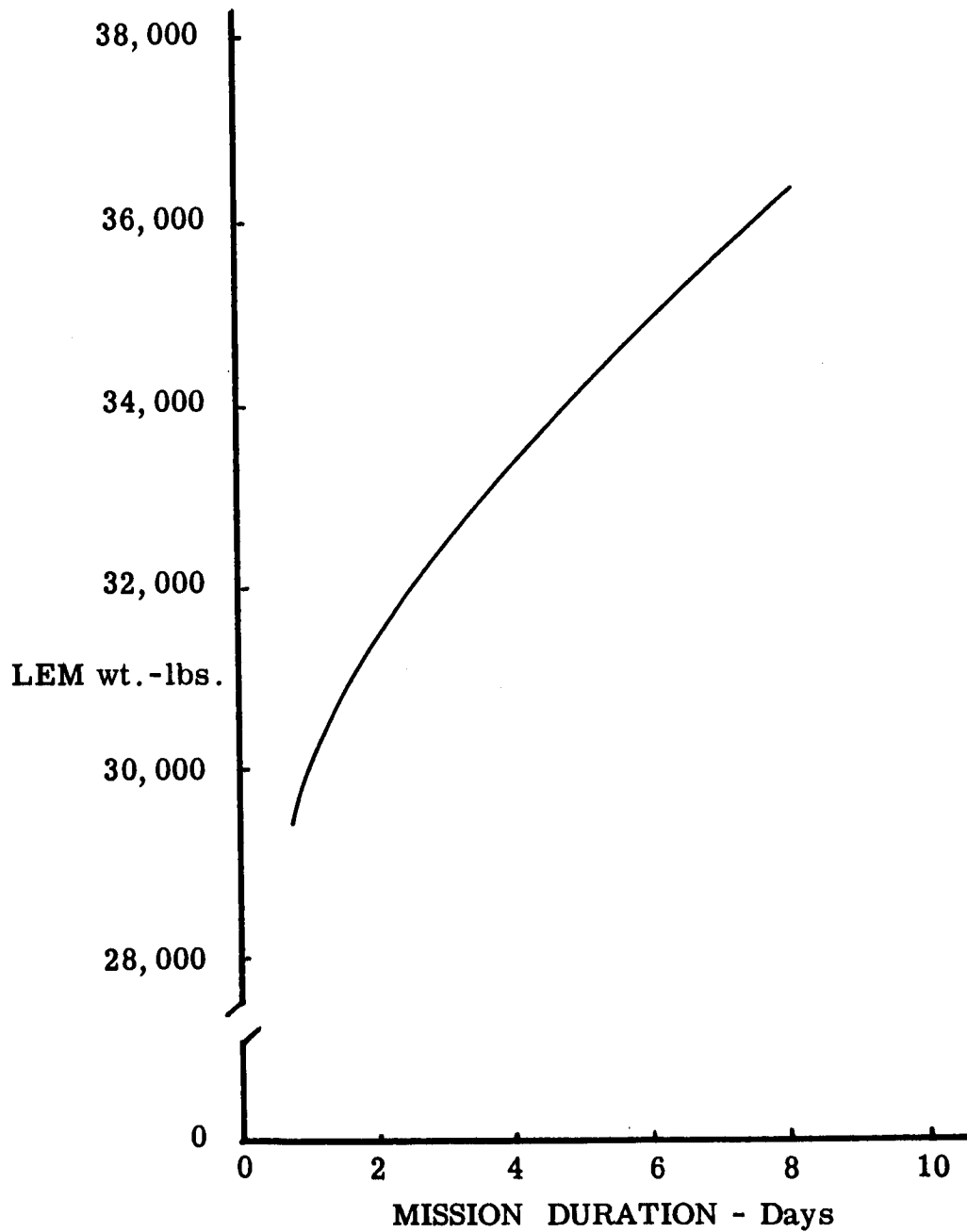
The weight change is due to:

(1) Systems which change in concept and/or complexity

    (a) Navigation and guidance
    (b) Communications
    (c) Instrumentation
    (d) Displays and controls
    (e) Crew support
        1. Extra garments
        2. Toilet articles
        3. Sanitation device

(2) Systems which vary directly with time.

    (a) Environmental control
    (b) Electrical power
    (c) Crew support
        1. Water
        2. Food

(3) Systems which grow as a result of the foregoing

    (a) Structure
    (b) Reaction controls
    (c) Landing gear
    (d) Propulsion

Cold Side Vs. Hot Side Operation

The penalties associated with operation of the LEM on the hot side of the moon are listed in Table 17-IV. Part of the weight penalty is associated with slightly increased cooling requirements. However, the major cause is the difficulty connected with rejecting heat to the very high temperature of the lunar environment.

TABLE 17-IV
COLD SIDE VS. HOT SIDE OPERATION WEIGHT PENALTIES

Basic Δ Weights to Existing Components to go from Cold Side to Hot Side	Mission Duration	
	24 Hours	7 Days
Radiator	42	162
Shutters for Windows	25	25
Insulation for Structure	0	14
Water	48	100
Water Tankage	5	12
Insulation for "Black Boxes"	5	5
Sub Total	125	318
Growth Factor -- 25% of Sub Total	31	80
Crew Station - Total Penalty	156	398
Propulsion Stage Penalty -- For Carrying Extra Weight of Crew Station	594	1527
LEM - Total Weight Penalty	750	1925

Staging

For a fixed set of ground rules (ΔV, I_{sp}, ϵ, etc.) a graph (Fig. 17-9) has been constructed to indicate the effect of incremental weights on the total LEM weight. Several examples are shown to indicate the value of a pound at different points in the mission. The method of using the plotted data is also explained.

(1) Weight carried from lunar orbit to the lunar surface costs one pound per pound of payload.

(2) Weight carried from lunar orbit to the lunar surface and back to lunar orbit costs approximately four pounds per pound of payload.

(3) Weight carried from the lunar surface to lunar orbit costs approximately two pounds per pound of payload.

EXAMPLE -- The payload at the start of the mission is increased 300 pounds but 100 pounds of this is staged or off-loaded on the moon.

The penalty to land the 300 pounds on the moon   =   300 lbs.
The penalty to launch the 200 pounds off the moon =   400 lbs.
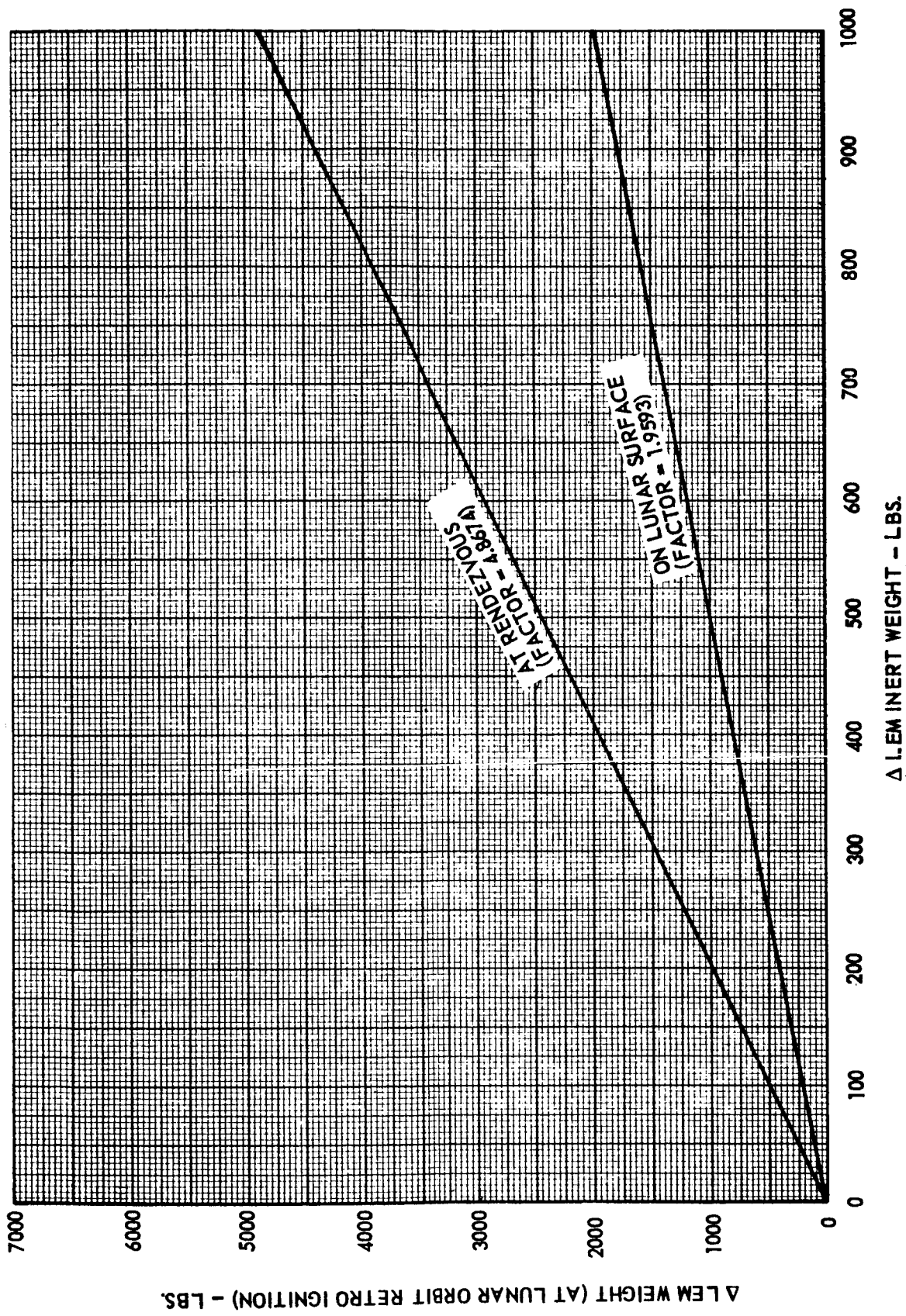   Total Penalty   =   700 lbs.

Figure 17-9 WEIGHT PENALTY RELATIONSHIPS – LEM

This can be found by going out to 300 lbs. on the Abcissa, up to the "On Lunar Surface" line, then over to the ordinate and reading 600 pounds total, which includes the original 300 pounds. Next go out to 200 pounds on the Abcissa and at this point, read the difference on the ordinate between the "On Lunar Surface" and "At Rendezvous" lines. This value is 600 pounds, including the original 200 pounds.

EXAMPLE -- The ratio between a system weight to be landed and that to be launched must be in the ratio of 1.48 to 1 pound, to just break even.

System "A" weighs 119 pounds and is carried all the way through the mission at a cost of 580 pounds.

System "B" weighs 148 pounds during descent but only 100 pounds at ascent. The total cost of this system is also 580 pounds.

On the Abcissa of the graph, at Δ weight of 119 pounds, go up to the "At Rendezvous" line, across to the ordinate and read 580 pounds.

At 148 pounds on the Abcissa, go up to the "On Lunar Surface" line, across to the ordinate, and read 290 pounds. Then at 100 pounds on the Abcissa, read on the ordinate the difference between the "On Lunar Surface" and "At Rendezvous" lines. This value is 290 pounds, giving a total of 580 pounds.

Weight changes realized in the LEM also affect the Service Module propulsion which results in a change to the overall spacecraft weight. This relationship is shown in figure 17-10. For example, if the LEM inert weight decreases by 300 pounds, the spacecraft weight will decrease 1225 pounds. The same type of procedure is used here as was previously detailed for figure 17-9.

In the event that it becomes desirable to return the LEM to near earth space, additional propellant will be required in the Service Module to escape lunar orbit. The effect of accelerating the greater weight spacecraft is shown in figure 17-11. The weight change includes the penalty for carrying the additional propellant and tankage translunar also.

Δ LEM INERT WEIGHT – LBS
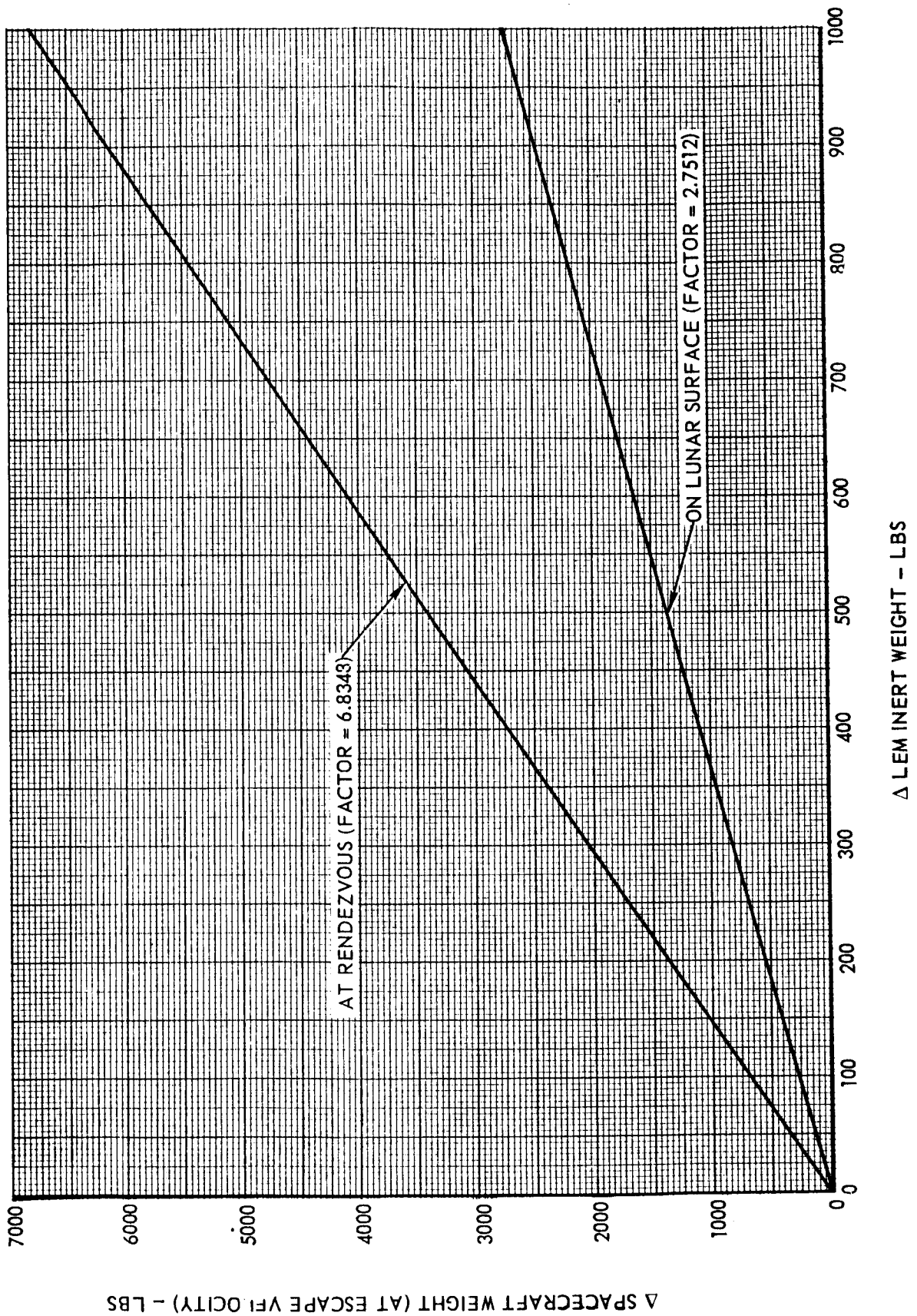
Figure 17–10   WEIGHT PENALTY RELATIONSHIPS-SPACECRAFT

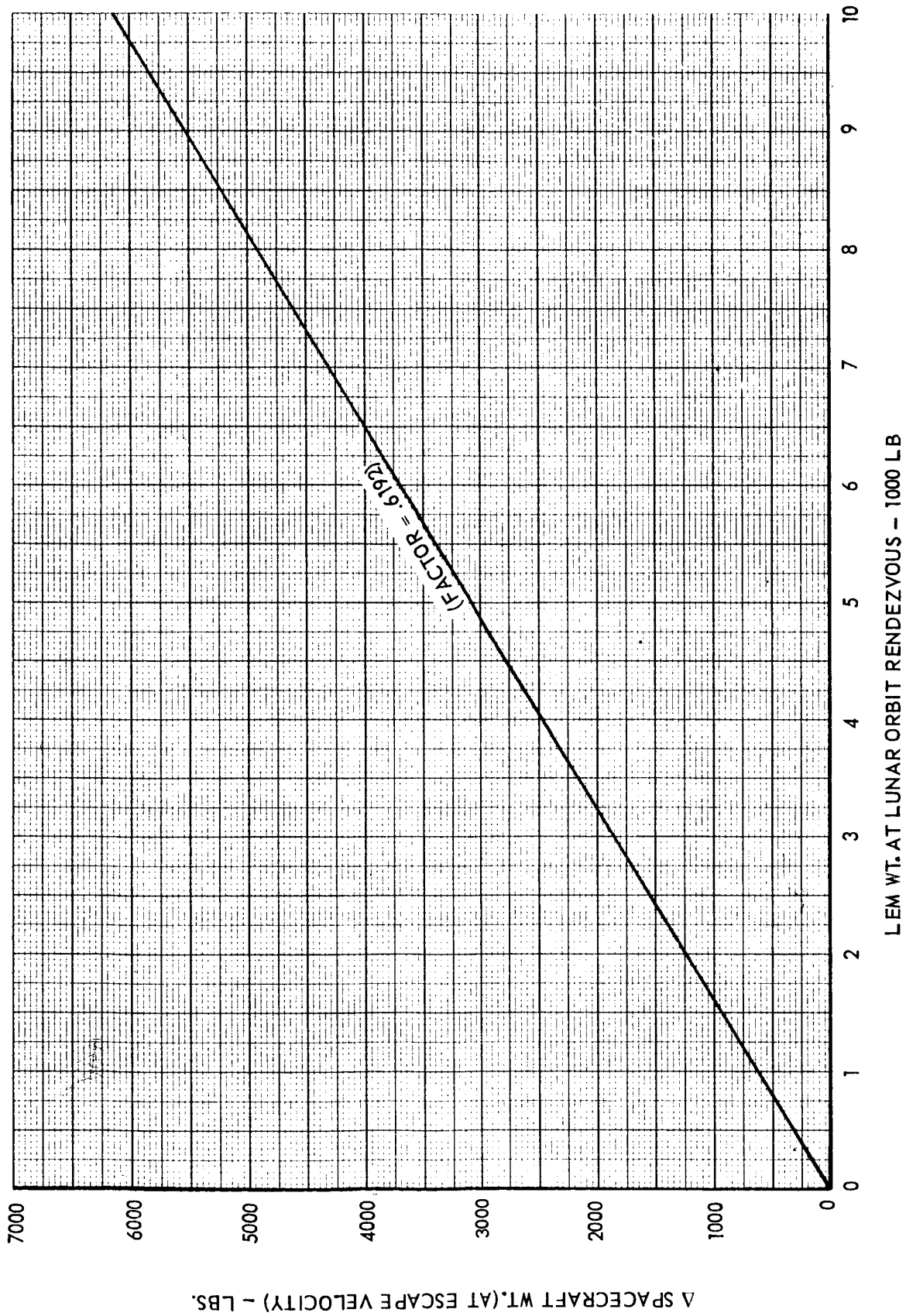Δ SPACECRAFT WEIGHT (AT ESCAPE VELOCITY) – LBS

Figure 17-11 WEIGHT PENALTY FOR RETURNING LEM TO NEAR EARTH SPACE
(ADDITIONAL SERVICE MODULE PROPELLANT & TANKAGE)

TABLE 17-V

CONCEPTUAL DESIGN WEIGHT SUMMARY

CONCEPT CODE	11-C	11-D	11-E	11-F	11-G	11-H	11-J	6-K	10-K	11-K	13-K	14-K	12-X	12-L
LEM	24,698	15,356	16,806	6,250	13,071	19,822	32,212	12,092	12,092	26,995	10,659	10,659	34,633	29,299
Crew Station	(4,790)	(2,917)	(4,790)	(1,844)	(2,351)	(5,118)	(5,905)	(3,914)	(3,914)	(3,914)	(3,914)	(3,914)	(4,877)	(4,989)
Structure	1,200	985	1,200	697	985	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,506	987
Systems	3,590	1,932	3,590	1,147	1,366	3,368	3,557	1,968	1,968	1,968	1,968	1,968	2,244	2,883
Growth Allowance	0	0	0	0	0	550	1,148	746	746	746	746	746	1,127	1,119
Landing System	(655)	(420)	(529)	(200)	(362)	(628)	(855)	(624)	(624)	(720)	in RetMod	in RetMod	(1,307)	(975)
Propulsion	(19,253)	(12,019)	(11,487)	(4,206)	(10,358)	(14,076)	(25,452)	(7,554)	(7,554)	(22,361)	(6,745)	(6,745)	(28,449)	(23,335)
Inert	1,118	700	705	355	602	1,169	1,425	814	814	1,180	799	799	3,000	2,157
Propellant	18,135	11,319	10,782	3,851	9,756	12,907	24,027	6,740	6,740	21,181	5,946	5,946	25,449	21,178
ADAPTER. LEM-to-S-IV B	2,000	1,275	2,000	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,491	3,230
SERVICE MODULE	38,300	38,300	38,300	29,289	33,398	38,300	42,918	38,300	38,300	38,300	38,300	39,963	40,628	40,131
Inert	8,804	8,804	8,804	8,584	8,804	8,804	8,917	8,804	8,804	8,804	8,804	8,845	8,561	8,669
Propellant	29,496	29,496	29,496	20,705	24,594	29,496	34,001	29,496	29,496	29,496	29,496	31,118	31,977	31,462
COMMAND MODULE	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,156	10,475
RETRO MODULE								88,598	65,369		101,191	21,934		
Inert								10,489	8,195		13,510	3,372		
Propellant								78,109	57,174		87,681	18,562		
RETRO MODULE ADAPTER								860	860		860	520		
SPACECRAFT WT.	75,198	65,131	67,306	47,789	58,719	70,372	87,380	152,100	128,871	77,545	163,260	85,326	87,908	83,135
LEM DESIGN DATA														
No. of Crewmen	2	2	2	1	2	2	2	2	2	2	2	2	2	2
Lunar Stay Time	160 hrs.	218 min.	160 hrs.	218 min	218 min	160 hrs.	160 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs
Landing Side	cold	cold	cold	cold	cold	cold	hot	cold	cold	cold	cold	cold	cold	cold
Reserve Propellant	2%	2%	2%	0	2%	5%	5%	12%	12%	12%	12%	12%	12%	9%
Unavailable propellant	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	1%
Type of Propellant	storable	storable	cryogenic	cryogenic	storable	cryogenic	storable	storable	storable	storable	storable	storable	storable	storable

17.5   RESERVE PHILOSOPHY

There is a requirement for reserves in systems which have expendables because of variations in consumption resulting from various causes. From the standpoint of mission success, such variations which lead to degradation of performance or complete inability to perform, cannot be tolerated. It is therefore necessary to study such systems to determine where and when the consumption variations are likely to occur and then, to determine what provisions are required to maintain a dependable system. This is truly the reserve philosophy; to maintain a dependable system through conservative, practical, design approaches.

In the following paragraphs, the reasons for and quantity of reserves are enumerated for each system separately.

17.5.1   Electrical Power System

Provides redundant energy sources:

(1) Because it has a 33% redundancy in fuel cells.

(2) It includes 10% excess in all expendables.

(3) It includes a 100% redundant battery system.

Any two of the three fuel cells can supply the vehicle electrical power during any mission phase. During the stay on the lunar surface, any one of the three fuel cells is capable of supplying the electrical power required. One failure of a dynamic component will not effect the system operation. However, two dynamic failures require an aborted mission even though their failure is not catastrophic. The 10% propellant reserve will allow power to be provided at a 10% higher level for the normal duration or for a longer duration at the same level. Since the power required tolerance band on electrical equipment is approximately 10%, the selection of this value coupled with the other contingencies is in keeping with the conservative approach for the HS-625 vehicle.

Dual batteries were selected for the ascent phase on the basis of mission success. Even though the silver-zinc units have reliability values approaching .996, we are not willing to chance the inability to launch because of lack of battery power if only one was carried and it failed. Normally it is logical to assume that lighter weight batteries could be obtained if reliability could be sacrificed. However, the silver-zinc batteries already combine light weight with high reliability.

A single fuel cell is not capable of supplying sufficient ascent power and therefore cannot take the place of a battery. If a single fuel cell could furnish the required power, the staging philosophy would have to be altered since the cells are attached to the landing gear which remains on the lunar surface.

17.5.2   Environmental Control System

Provides capability beyond the normal requirement by including additional oxygen:

(1) To replace the oxygen lost through leakage.

(2) To surpass the normal requirement and the leakage allowance by 50%.

An extrapolation of Mercury data indicates that designing for a leakage rate of 0.1 pounds per hour is a reasonable objective. Therefore, excess oxygen is supplied to replace the oxygen lost at this rate.

Studies made in the Human Factors area indicate that under normal conditions an astronaut be allowed to remove his pressure suit after 24 hours. To accommodate the astronauts in this mode, one cabin pressurization is required. Conservatively, the HS-625 ECS provides for two cabin pressurizations, in case the de-suiting procedure must be repeated.

Under normal usage it is foreseen that the airlock will be cycled on the lunar surface twice by each man. Since the ECS backpacks provide up to four hours of sustenance, each man will be capable of remaining outside the capsule for nearly eight hours. The number of reserve airlock cycles are not clearly defined because they depend upon the amount of unused reserve oxygen remaining at the time the additional airlock cycling is required.

To account for the oxygen lost due to movement of the crew within the pressure capsule, meteorite punctures, faulty seals, etc., a supply of oxygen, 50% in excess of the basic requirement, is carried in the HS-625 vehicle. This is the same allowance made in the APOLLO vehicle; in both cases the allowance is based on engineering judgement in considering the many unknowns.

A four-hour emergency oxygen supply--more than enough for the normal ascent phase--is also provided.

17.5.3   Reaction Control System

Provides for emergency by including:

(1) 12 percent excess propellant

(2) redundancy in system components

(3) redundancy in plumbing

Since the determination of use rate, manual operation requirements, and mixture ratio shift are difficult to predict, a growth allowance of 12 percent in propellant weight was provided to cover these contingencies. This figure is based on a 6 percent allowance for manual operation and 2 percent allowance for mixture ratio shift. The remaining 4 percent is

based on engineering judgement in allowing for use rate and unknowns. In addition to this, the initial propellant loads were estimated conservatively.

Based on the philosophy that a double failure of a dynamic component requires an aborted mission, redundant regulators, valves and engines as well as double plumbing paths were provided.

17.5.4   Propulsion System

Reserve propellant is required for the following reasons:

(1) ΔV_I requirement--deviation from nominal mission

(2) Mixture ratio shift

(3) Manual and automatic control wastage

(4) Unavailable propellant

The results of a machine analysis of a nominal trajectory with one engine out indicates that at the worst possible point, the propellant required increases approximately 8 percent above normal due to an increase in ΔV_I required.

The reserve propellant required for mixture ratio shift was determined from the consideration that control devices will be installed in the propellant feed system which will assure 98 percent accurate control of the oxidizer-to-fuel usage ratio.

Results of simulator tests indicate that the propellant required for manual control of the descent and ascent trajectories is approximately 6 percent greater than the propellant required as calculated from ideal velocity change considerations.

A rigorous analysis of the tankage and feed system was not performed to determine the amount of unavailable propellant. Based on Atlas and Saturn experience, it was assumed to be 1 percent of the consumed propellant.

Based on the foregoing considerations, a reserve allowance of 10 percent of the consumed propellant was provided for descent and for ascent. From an engineering and probability standpoint, it was calculated that for the nominal mission, approximately 2 percent of the (10 percent) descent reserve would not be used. This amount would be transferred to the ascent tanks to be used as reserve propellant for the ascent phase. (This scheme was conceived to avoid the weight penalty associated with carrying "payload" to the lunar surface). The difference between the transferred propellant and the total ascent reserve required would be provided so the total would be 10 percent. This is shown in the following illustration.

(1) Descent consumed propellant = 14,620 pounds

Reserve = 10% of consumed = 1,462 pounds

Reserve used on nominal mission = 8-9% of consumed = 80-90% reserve = 1220 pounds

Reserve remaining = 1,462 - 1,220 = 242 pounds

(2) Ascent consumed propellant = 4,842 pounds

Reserve = 10% of consumed = 484 pounds

Propellant remaining from descent = -242 pounds

Additional reserve required = 242 pounds

Therefore 242 pounds or $\dfrac{242 \times 100}{4,842}$ = 5% of the ascent consumed is required to bring the total reserve to 10 per cent. It should be noted that the 242 pounds of descent reserve remaining is $\dfrac{242 \times 100}{14620}$ = 1.65% of the descent consumed, while it is 5% of the ascent consumed.

In a remote case when the entire 10 per cent of descent reserve propellant is used, the mission would be modified by decreasing the lunar stay time so that a minimum velocity change would be required for the ascent trajectory. The 5 per cent reserve should be sufficient under these conditions.

ABSTRACT

This volume contains the Weight Analysis of the HS-625 vehicle. It includes weight and balance data on the selected configuration plus weight justification, not usually offered in a study report. The results of parametric studies are presented in summary form, while the reserve philosophy is detailed.